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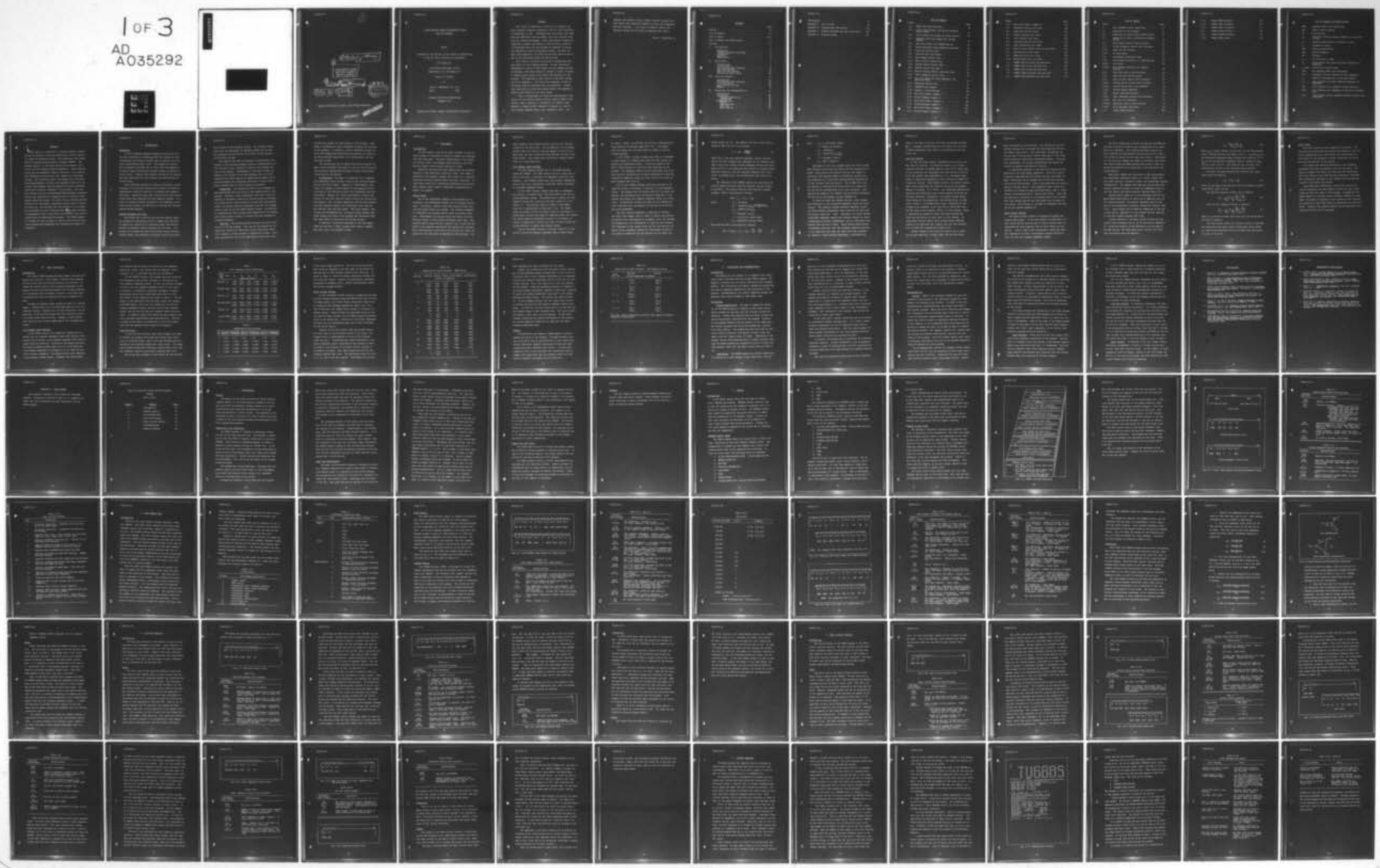

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A USER-ORIENTED POWER
DISTRIBUTION SYSTEM
ANALYSIS PROGRAM.

THESIS

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10 Jesse Allen Underwood, Jr
~~Major~~ ~~USAF~~

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A USER-ORIENTED POWER DISTRIBUTION SYSTEM ANALYSIS PROGRAM

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by

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Graduate Electrical Engineering
December 1976

Preface

This thesis is basically a revision to a digital computer program originally prepared at the Air Force Institute of Technology in 1975. Although minor corrections have been made and additional features added, the basic program structure has remained unchanged. Since the original program was completed, students and faculty at the Air Force Institute of Technology have used the program for analysis of actual and theoretical power distribution systems. The many comments and suggestions received from the users have served as one of the motivating forces for the revision.

This thesis is written to be used in conjunction with the thesis for the original program. As only theoretical development is given in this thesis for the changes and added features, both these should be studied in order to obtain a complete description of the theory and operation of the program. The highlight of this thesis is the User's Guide, listed as Appendix A. The thesis was purposely written so the guide could be withdrawn and used separately. Anyone only interested in using the program should find Appendix A complete and sufficient for their needs.

I wish to acknowledge all those who contributed to the success of this thesis project with my special thanks to my advisor, Capt. Frederick C. Brockhurst; my readers, Capt. Michael A. Aimone and Mr. Charles W. Richard, Jr.; and to the original program author, Capt. Michael C. Heer. The

comments and guidance from my advisor and the original program author were especially helpful in doing the background work and research. I also wish to thank my typist, Mrs. Charlette Kjesbo for her help in preparing this thesis.

Jesse A. Underwood, Jr.

Contents

List of Figures

List of Tables

List of Symbols and Abbreviations

ACSR	Aluminum Cable Steel Reinforced.
ANG	Angle, usually degrees.
CM	Circular Mils
D_e	Equivalent spacing between conductors or neutrals in feet.
D_s	Geometric mean radius of neutrals in feet.
f	Frequency in hertz.
GMR	Geometric Mean Radius
KVA	Kilovolt-Amperes
KW	Kilowatt
r_a	AC resistance in ohms
r_e	Zero sequence and earth resistance component of impedance
ρ (rho)	Resistivity in meter-ohms
TCUL	Tap Changing Under Load Transformer
X/R	Impedance ratio of reactive to real impedance.
x_a	Inductive reactance out to one foot radius.
x_e	Zero sequence and earth inductive component of impedance.
ZOA	Zero sequence of a conductor without neutrals.
ZOAG	Zero sequence self impedance of neutrals or ground wires.
ZOG	Zero sequence mutual impedance between neutrals and conductors.

Abstract

This paper is a revision of a digital computer program written to perform a load flow and/or short circuit analysis of a power distribution system. The program has been named Power Distribution System Analysis Program (PDSAP). The program capacity is 250 buses and 500 line elements, with 250 of the line elements being transformers. Input routines accept data as impedances (ohms or per-unit), or as descriptive information such as wire size, length, or transformer ratings. For descriptive data, the program uses pre-calculated approximations to derive the impedance values for the various line elements and the program will adjust impedance values due to neutral conductors in the system. The load flow routine uses the fast-decoupled Newton-Raphson technique and has the capability of changing loads to represent load growth within the system. The short circuit routine analyzes systems in 50 bus groups, simulating various types of faults for each bus. Bus voltages and line currents in the system are calculated for each simulated fault. The paper contains a comprehensive User's Guide which provides clear and concise instructions for operating the program. The PDSAP program is intended for use by anyone in the Air Force with an electrical engineering background and concerned with power distribution.

I. Introduction

Background

In 1975 a digital computer program was written at the Air Force Institute of Technology that was capable of simulating power distribution systems such as found at most Air Force installations (Ref 2:xii). The program was successfully designed to provide the Air Force with the capability to analyze power distribution systems without incurring excessive costs. However, the original version of the program had some characteristics that limited its applicability in certain cases.

Since efficient operation of power distribution systems continues to be of great interest and concern, the need for comprehensive analysis capability at minimum cost remains a valid goal. During the past year, several power distribution systems have been simulated with the computer program. As a result of certain problems encountered in attempting to simulate actual systems, the necessity of revising the original program became apparent.

Problem Statement and Scope

The problem was to analyze the existing digital computer program and investigate possible changes and additions to improve the capability of simulating power distribution systems as generally found throughout the Air Force. The program was re-named the Power Distribution System Analysis Program, PDSAP, and modified to overcome certain limitations

that existed in the original version. Two of these limitations were the adjustment of impedance values for systems with neutrals and the ability to do short circuit analysis on non-radial systems.

The scope of the work was limited to modifications and changes of the existing program structure, endeavoring to retain the basic logic structure as used in the original version of the program. Additionally, a new User's Guide, Appendix A, was written to aid and encourage the use of the program by Air Force electrical engineering personnel in resolving problems and increasing efficiency of power distribution systems with as little expense as possible.

Assumptions: The assumptions used in the original program preparation were also used in this modification of the program. Basically, these assumptions were that a one-line diagram of the power system to be studied would be available for a data source, that accuracies in load-flow calculations within ±10 percent would be reasonable, and that the program would be used on the CDC CYBER computer system. An additional assumption was that systems being simulated in the program were either actual systems or systems that were designed to accepted standards.

Approach: The existing digital program was used as the basis for the new program. Each area of the program was examined and tested with additional system simulations taken from textbooks, actual systems or theoretical systems. Problems identified by use of the additional systems were cate-

gorized into groups for each routine in the program. Each group of problems was then considered in making the revision to the program. In addition, several different persons utilized the program and difficulties encountered in coding input data provided suggestions to be incorporated into the new User's Guide.

The overall goal was to modify the existing program to make it more versatile and useful to the Air Force by assisting electrical engineering personnel in power distribution system analysis and design.

Presentation: The paper is organized into 4 chapters with appendices which include a copy of the revised program and the new User's Guide. Chapter II, "Development," discusses the changes to each routine in the program with the inclusion of the theoretical basis for information that has been added. Chapter III, "Tests and Results," details the results of test data that was used to verify the accuracy of the program. This includes comparison with the test results from the original program, plus additional tests used for new routines that have been added. The final chapter, "Conclusion and Recommendations," discusses future changes that would enhance the value of the program and limitations that have been found to exist with the revised version.

In addition, information contained in the four appendices are the User's Guide, program logic charts, program data flow charts and program listing.

II. Development

Introduction

In this chapter, each of the major routines in the original program is discussed in terms of changes and additions that have been made. The major subdivisions of the chapter are Control Cards, Line Element Input Routines, Load Flow Routine, Short Circuit Routine and User's Guide.

Equations utilized have been adapted from the original program or from additional sources as cited. The reader is referred to the original program (Ref 2:190) for a complete discussion on basic program theory and logic structure. In cases where there was a significant modification to the original program logic, there is additional documentation to support the changes.

Control Cards

One of the significant changes in the program was to introduce a new standardized format for all program control cards. Previously, control cards were varied in both location and format within the program. The revision attempted to standardize all program control cards to prevent confusion. Additionally the control cards are used as an error checking routine to help prevent erroneous input data. The program control cards all use a keyword that is read and compared to the expected word before the program will continue. Errors and omission in the use of the keyword will cause the program to halt and print an appropriate error message. An-

other change to the program control cards was the location relative to the data cards. By the addition of one program control card, all control cards now appear in front of the data cards for each routine and help identify the data cards which follow. This scheme also facilitates finding control cards in a large data deck.

Line Element Input Routines

Two line element routines are in the PDSAP program, LINEZ and LINDATA. The LINEZ routine utilizes input data in ohms or per-unit to calculate all impedance values for line elements. The LINDATA routine uses line element information such as wire size, transformer rating and similar variables to calculate impedance values.

In the LINEZ routine, changes were made to compensate for neutral, or ground wires, that would affect the zero sequence impedance values. The method used to adjust the zero sequence values was to multiply the given values by a constant, 2.7. The constant value was taken as the higher value for a representative range (Ref 7:21). The higher value was chosen to give the lowest value for the phase-to-ground fault current that might be expected within the system. The lowest phase-to-ground fault current is of primary interest in being able to detect this type of fault within the system relative to normal load current values.

Also in the LINEZ routine, a constant value of 3.5 was used to create zero sequence impedance when no input value

was given. Again, the constant was used as a representative value based on an average range (Ref 7:21). The higher value was chosen for the same reason as cited in the preceding paragraph.

In the LINDATA routine, changes were made to accomodate a larger number of standard wire sizes for both aerial conductors and underground cable. A table was added in the User's Guide listing all the wire sizes available in the program. The impedance values for the additional wire sizes were based on interpolation of curves generated by using representative impedance values for wire sizes used in the original program (Ref 3:19-20)

Also in the LINDATA program, provision was made to include the effects of grounds, or neutrals, on the impedance values. The program uses the values given for the phase conductors, and information for the neutral conductors, to determine the proper zero sequence impedance values for aerial lines. An additional section was added to the LINDATA routine to perform this calculation as detailed in the following three paragraphs.

The zero sequence impedance is adjusted as follows: The input line element card is coded to reflect the presence of neutrals with information as to number, size, and spacing. The program uses this information to find the zero sequence self-impedance of the ground wires, Eq (3), and the zero sequence mutual impedance between the three-phase circuit as one group of conductors and the neutrals as the other con-

ductor group, Eq (2). The equation for one circuit with n neutrals (Ref 8:44-45) is as follows:

$$ZO = ZOA - \frac{(ZOAG)^2}{ZOG} \qquad (1)$$

where ZOA is the zero sequence impedance without neutrals, ZOG is the zero sequence self impedance of the neutrals, and ZOAG is the zero sequence mutual impedance between the three-phase circuit as one group and the neutrals as another group. With this equation, the zero sequence impedance for n neutrals, or ground wires, can be determined with relative accuracy.

The addition to the LINDATA routine was constructed to utilize values and logic from the original routine as much as possible. *The value of ZOA was used from the original* program. ZOAG is calculated as follows:

$$ZOAG = r_e + j(x_e - 3x_d) \qquad (2)$$

where

$$r_e = .004764(f)$$

$$x_e = .006985(f)\log_{10}\left(\frac{4.6655(10^6)\rho}{f}\right)$$

$$x_d = .004657(f)\log_{10}D_e$$

f = frequency (hertz)

ρ = resistivity (meter-ohms)

D_e = equivalent spacing (feet)

The value for ZOG is calculated as follows:

$$ZOG = 3/n(r_a) + r_e + j\left(x_e + \frac{3x_a}{n} - \frac{3x_d}{n}\right) \qquad (3)$$

where r_a = ac resistance (ohms)

n = number of neutrals

$r_e = .004764(f)$

$x_a = .004657(f)\log_{10}\left(\frac{1}{D_s}\right)$

and f = frequency (hertz)

D_s = GMR of neutrals

Adjustment to the zero sequence value can also be made when neutrals are present but their size and spacing are unknown. When neutrals are present and only the number is specified, the program assumes an equivalent spacing from the conductors of 4 feet and a spacing between neutrals of 15 feet for more than one neutral. The assumed wire size for neutrals is 105,500 CM (Circular Mils) for copper and 133,100 CM for aluminum when size is not specified. This addition was added to the LINDATA routine between statements 230 and 300 of the program listing (Appendix D).

In both the LINEZ and LINDATA routines, minor changes were necessary to the calculated impedance values for transformers. The original program contained impedance values for three-winding transformers which could not be used with the present input data format. Therefore, all three-winding transformer impedance values were blocked, except for three-winding phase-shifting transformers, and all references were deleted from the User's Guide. Three-winding phase-shifter transformers that have only two windings connected externally are compatible and codes for these have been retained. To simulate a three-winding transformer, a procedure was

added to the User's Guide to use three two-winding transformers. Although blocked from use, the values for all three-winding transformers were left in the program for possible future use.

Load Flow Routine

In the Load Flow routine, convergence with certain systems can be a problem. By extensive testing with several simulated systems, it became apparent that if the loads within the system are not reasonably well distributed or the R/X ratio was greater than approximately 1.5, convergence sometimes is impossible regardless of the tolerance or number of iterations allowed. From limited analysis of several systems, under these conditions the simulated system in the program appears to diverge. As a result, the *difference* between the specified and calculated power becomes greater with each additional iteration. Eventually, the numbers become larger than allowed by the program and a processing error, or mode error, results. To prevent mode errors, limitation on the voltage array elements, V (I), was set at ±100.00 per-unit and the angle array elements, ANG(I), at ±30π radians. Also, a limitation was placed on Theta, the angle between the start bus and end bus of each line, at ±30π radians. By using these extreme limits, most systems being simulated should not be affected, but systems that will not converge will not halt the program with a mode error.

Another change to the Load Flow routine was to print the voltage magnitude, voltage angle, DLP and DLQ values

when convergence is not obtained. DLP and DLQ are the differences between the calculated and specified real and reactive power respectively. This additional information can aid the user in being able to detect what parts of the simulated system are causing the convergence problem. By using this information, the system configuration can usually be altered to obtain a satisfactory solution.

A significant addition to the Load Flow routine was the addition of the load change capability. After the initial system has converged and the results printed, any number of Type I load buses can be changed and the Load Flow routine run with the revised data. Type 1 load buses have no restrictions on voltage limits. Only changes to Type 1 buses are allowed as to change voltage controlled buses, Type 2, would require recalculating the B'' matrix (Ref 4:863). After the new solution is obtained, it is printed with a list of buses that were changed and the new load values for all buses in the system. This routine is included in statements 580 thru 600 of the program (Appendix D).

<u>Short Circuit Routine</u>

The Short Circuit routine as originally designed had several limitations. It was only capable of analyzing a radial system and the process used to select various buses as subsystems for fault analysis did not have repetitive capability. Lastly, some of the transformers connection codes were apparently in error, occasionally causing invalid results for the zero sequence impedance values.

The first change was to modify the BUS and and BUSØ subroutines to allow a system of any configuration to be satisfactorily simulated. This required extensive analysis of these routines and considerable testing with various simulated systems to insure the new logic was correct. Additionally, the necessary changes were made to initialize the arrays each time the BUS and BUSØ routines were called, which corrected the problem of not being able to run successive subsystem studies.

Some minor changes were necessary in the routine where the transformer connection codes, or C values, adjust the line table entries to properly reflect the transformer winding configuration. The changes were made and testing done with various simulated systems to insure the impedance values in the line tables were being correctly adjusted (Ref 3:25).

Another minor change was to the equations used for the phase-phase-ground faults as there was an apparent error in the original program. The present equations used in this part of the program were carefully checked for accuracy (Ref 3:10). Logic changes can be noted by comparison of the logic flow charts, Appendix B or the program listing, Appendix D, with the original program (Ref 2:84).

A major addition to the Short Circuit routine was the section from statements 135 to 148 of the program (Appendix D). Using the elements of the ZBUS matrix as developed by the BUS routine, the three-phase fault currents for lines were calculated using the equation:

$$I_{se} = \frac{Z_{sk} - Z_{ek}}{Z_{line\ se}} \frac{1}{Z_{kk}} \tag{4}$$

where I_{se} is fault current, in per-unit, on the line between S and E (SB and EB) with the fault at bus K. Z_{sk} and Z_{ek} are the calculated impedance values between bus K and bus S or E. Z_{kk} is the driving point impedance value or diagonal value, of bus K (Ref 1:26-27). The lines are any existing lines between buses listed in the subsystem being analyzed.

Likewise, the phase-ground fault currents were calculated using the equation

$$I_{se} = 2I^{+}_{se} + I^{0}_{se} \tag{5}$$

where I^{+}_{se} and I^{0}_{se} are the positive and zero sequence currents respectively (Ref 1:78-79).

The positive sequence current, I^{+}_{se} is found by

$$I^{+}_{se} = \frac{1}{2Z^{+}_{kk} + Z^{0}_{kk}} \frac{Z^{+}_{sk} - Z^{+}_{ek}}{Z^{+}_{line\ se}} \tag{6}$$

and, the zero sequence current is found by

$$I^{0}_{se} = \frac{1}{2Z^{+}_{kk} + Z^{0}_{kk}} \frac{Z^{0}_{sk} - Z^{0}_{ek}}{Z^{0}_{line\ se}} \tag{7}$$

where K is the bus at fault and S and E are the SB and EB of the line in question.

The line current values are stored in arrays CU and CUR for three-phase and phase-ground respectively these values are then printed following the bus voltages when the proper OUT code is selected.

User's Guide

The User's Guide has been completely re-written. The revision was written with the concept that anyone in the electrical engineering field could follow the instructions for utilization of the program to include preparation of the input data and analysis of the results.

All changes and additions discussed in the preceding paragraphs have been incorporated into the new guide. The layout of figures and tables was done with the expectation that these might be extracted and used separately, therefore much information contained in the writing was purposely duplicated in the tables and figures.

Some additional information, such as wire tables and current equations, has been added to assist the user in preparing the data for input to the program. Although the CDC CYBER computer is the only system presently capable of using PDSAP, the guide is designed so that persons at any location can prepare the input data based on instructions in the User's Guide. Likewise, the output products can be analyzed at any location with the aid of the guide.

III. Tests and Results

Introduction

The overall PDSAP program had many changes and additions during this revision. Each change or addition was implemented and tested until the desired accuracy was achieved. Although the results cited in the following paragraphs do not compare exactly with published results for the same problems, it is noteworthy that the degree of error is tolerable given to inaccuracies that are inherent with such a computer program.

Testing of simulated large systems was done to a limited degree. Systems with up to 167 buses have been run with satisfactory results. However, due to time limitations, not all functions of the revised program have been completely tested on systems larger than 130 buses. Changes in each routine were tested and the results summarized in the following paragraphs.

Line Element Input Routines

In the LINEZ routine, the significant changes were to modify the zero sequence impedance values when neutrals were present and to assume a zero sequence impedance value when no input value was specified. Testing for the change consisted of using an example problem (Ref 7:2-34 to 2-43) where the zero sequence impedance was assumed to be 3.5 times the positive sequence impedance. The program values were identical to the example problem values. Likewise, the same problem

was modified and the effect of neutrals on the impedance values was tested. The results were as expected; since a constant, 2.7, is used when neutrals are considered.

In the LINDATA routine, the changes were more extensive and designed to give greater accuracy in calculating the zero sequence impedance values. To test the routine designed to adjust the zero sequence impedance value for the affect of neutrals, a problem was especially designed to compare approximate values from a published table (Ref 3:14-15). The results of the comparison are given in Table I. The top figure is the published value and lower figure the program calculated value. The first two columns are the positive sequence impedance values, the next two the zero sequence values, and the last two the zero sequence values with neutrals. It should be noted that having the wide range of wire sizes available necessitates some approximations. However, as shown in the table, the difference is not of the magnitude that the program results would be in jeopardy.

Load Flow Tests

In the Load Flow routine, since minor changes were made to prevent the program from going into a mode error condition for certain systems, some of the same problems used for testing in the original program were again tested. The Stagg and El-Abiad System (Ref 5:284-299), shown in Fig. A-18, give the identical results as previously reported (Ref 2:41).

One of the major changes in the routine was the addition

Table I

Wire Impedance Value Comparisons

Wire Size (CM)	Type	R_1	X_1	R_0	X_0	R_{OG}	X_{OG}
		(ohms per mile)					
500,000	Cu	.1229	.6310	.4161	2.9600	.6922	1.9388
		.1190	.6332	.4047	2.9566	.6761	1.8711
300,000	ACSR	.3421	.6442	.6278	3.1590	1.0259	2.2429
		.3095	.6618	.5951	2.9852	1.0141	2.0901
250,000	Cu	.2571	.6732	.5428	3.0022	.8189	1.9811
		.2333	.6761	.5190	2.9994	.7903	1.9139
105,500	ACSR	1.1200	.8422	1.4061	3.3570	1.8200	2.5312
		.8856	.8284	1.1712	3.1518	1.6283	2.3853
83,690	Cu	.7651	.7461	1.0512	3.0751	1.3881	1.9811
		.6999	.7475	.9855	3.0708	1.3236	2.0758
66,370	ACSR	1.6901	.8511	1.8850	3.3660	2.3910	2.5402
		1.4093	.8570	1.6949	3.1803	2.1139	2.4235

Table II

Comparison of Bus Voltages

Bus	1st Run (Original)		2nd Run (Modified)		3rd Run (Original)	
No.	MAG(p.u.)	ANG(deg)	MAG(p.u.)	ANG(deg)	MAG(p.u.)	ANG(deg)
1	1.06	0.0	1.06	0.0	1.06	0.0
2	1.037	-2.6357	1.0364	-2.3942	1.037	-2.640
3	1.009	-4.7990	1.0082	-4.3160	1.009	-4.807
4	1.008	-5.1239	1.0064	-4.5358	1.007	-5.133
5	1.002	-5.9684	1.0012	-5.6227	1.002	-5.981

of the load change capability. This was tested using the same system by changing to new bus loads on the second run and then back to the original values on the third run. As noted in Table II, there are slight differences between the first and last result. However, the differences, probably introduced by rounding errors, should not measurably affect the overall program accuracy.

<u>Short Circuit Testing</u>

To test the Short Circuit routine, a comparison was made with the example problem called the DSPM System (Ref 3:40-44). The DSPM system is an 18 bus radial system with copper aerial conductors and aluminum underground cable, Fig. A-21. This system uses the LINDATA input routine to calculate impedance values. Table III shows the published values on the top line for fault currents and the PDSAP program calculated value on the second line. There was no zero fault impedance on faults for the underground cable and 20 ohms resistance for the aerial faults.

Analysis of the data reveals that the program values are very close to the published values in all cases. The largest error is approximately 2.2% on the Ph-Ph-Gnd(B) value for Bus 6. Considering the slight difference in conductor impedance values calculated by the program as shown in Table I, the accuracy of the Short Circuit routine is considered very good. This same problem was used for the original program (Ref 2:43). The calculated values for buses 1, 12, and 13 are very similar. The others vary as zero

Table III

Comparison of Fault Currents - DSPM System

Bus No.	3Ph-Gnd	Ph-Gnd	Ph-Ph	Ph-Ph-Gnd(B)	Ph-Ph-Gnd(C)
		(Values in Amperes)			
1	3123	3793	2705	3506	3720
	3123	3793	2705	3506	3720
2	2506	2947	2170	3068	2497
	2504	2944	2169	3065	2496
3	335	332	533	1822	1665
	336	332	535	1828	1670
5	294	277	414	913	799
	297	279	421	928	810
6	276	254	372	730	633
	280	257	379	746	643
7	0	240	0	0	0
	0	244	0	0	0
10	2244	2579	1944	2756	2083
	2243	2576	1943	2753	2082
11	2059	2322	1783	2518	1831
	2059	2319	1783	2514	1830
12	1924	2138	1666	2340	1650
	1923	2135	1665	2337	1665
13	1729	1879	1497	2082	1448
	1728	1876	1496	2078	1449
16	1972	2202	1707	2403	1721
	1971	2199	1707	2399	1721
17	0	2125	0	0	0
	0	2124	0	0	0

fault impedance was used previously for all buses.

Another test problem run with the Short Circuit routine was the Westinghouse example problem (Ref 7:2-34 to 2-43) to illustrate that a three-winding transformer can be simulated as three two-winding transformers and to verify the new line current routine. Fig. A-24, page 115 is a one line diagram of the problem. Using the procedure detailed in Appendix A, the three-winding transformer impedance values were converted to three two-winding transformers and input to the program through the LINEZ routine. The results are shown in Table IV. In this example problem, the text values were altered to reflect the positive and negative sequence values being equal. In Table IV, the text values are on the top line and the program values on the following line. The error between the values is less than 1% on the average. As the three-winding transformer was modeled differently in the program, no current magnitude comparison was made for the three-winding transformer buses.

Summary

The additions and changes to PDSAP appear to greatly enhance the value of the program. Although extensive testing in all areas was not permitted due to time constraints, several additional examples consisting of large and small systems have been simulated with success. In some cases, comparison data is not available, but indications tend to support the supposition that the program results are well within acceptable tolerances for all functions.

Table IV.

Comparison of Fault Currents - Westinghouse System

Line SB - EB	3Ph-Gnd	Ph-Gnd
	Current Magnitude in Amperes	
1 - 3	572.5	359.1*
	571.7	358.7
2 - 3	201.8	126.5
	202.0	126.7
3 - 4	1095.6	1124.9
	1095.1	1125.0
4 - 5	793.7	652.0
	793.6	652.2
5 - 8	535.5	335.6
	534.9	335.5

*All text values estimated on positive and negative sequence impedances being equal.

IV. Conclusions and Recommendations

Introduction

The purpose of this chapter is to summarize the significant results obtained from the revised PDSAP program. The chapter is divided into two areas, conclusions and recommendations. The conclusions will detail information gained from the project regarding capabilities and limitations of the program. Recommendations will detail suggested changes and additions that might be added at some future time.

Conclusions

Program Capabilities. The goal to expand the capability of the PDSAP program to simulate certain power distribution systems not possible with the original version was realized. Systems with neutrals and non-radial systems can now be successfully simulated with the program. Accuracy of the program improves with the quality of the input data, but results obtained from using the minimum data required will often suffice. The program has been exercised on simulating several different distribution systems, large and small, with the largest being 167 buses. Comparison of the program results with published data on sample problems shows that the PDSAP program has acceptable accuracy in both load flow analysis (Ref 2:41) and short circuit analysis (Ref 3:44).

Limitations. The PDSAP program has certain limitations. As pointed out by the original author (Ref 2:50), the pro-

gram uses a series impedance representation for the Load Flow routine and this may not be adequate for systems with large shunt admittances. Also, by experience, it has been proven that some systems can not be successfully simulated by the Load Flow routine. Changes to the program will prevent termination due to processing, or mode, errors; but the output data will be of questionable accuracy.

Another limitation with the Load Flow routine, is the program capability to simulate low voltage systems. The program was primarily designed to simulate high voltage (above 600 V) systems where the impedance ratio, X/R, was less than approximately 0.4. Problems where the R value was large compared to the X value tended to cause convergence problems. This limitation is not unusual, and has been encountered by others (Ref 4:868).

In the input data, certain limitations had to be placed on transformer winding configurations. As a result, three-winding transformers can not be simulated unless used as three two-winding transformers. With the limited number of three-winding transformers in use, this program limitation should affect relatively few prospective users.

At present, the program has no capability for transient stability analysis. Certain information, such as generator reactances, needed to determine the stability constraints of a system would have to be added before this feature could be included.

Most power distribution systems on Air Force installa-

tions use a mixture of single and three-phase circuits. At present, there is no provision in the program to simulate single phase branch circuits on a specified phase of a three-phase system. This can cause problems in adequately simulating the system where the attachment of single phase branch circuits will noticeably alter the load balance between phases.

Recommendations

General. PDSAP is an excellent program for power distribution system analysis, but additional capability would enhance its usefulness even further. As noted in the foregoing material, several additions and changes were made to the original program. Where practical, additions and changes were integrated into the existing logic structure to require as little additional computer memory space as possible. Although the revised program is apparently working accurately in all respects, it is recommended that before many more additions or changes are made, an attempt be made to condense the present program. For example, adoption of a dynamic memory allocation procedure would greatly increase the efficiency of the program. With this method, memory space would be allocated according to the size of the problem instead of using the maximum for every problem.

The recommendations cited by the original author remain valid (Ref 2:51-52) with the exception of those items incorporated into this revision. Especially the need for transient stability analysis and a line outage routine. Modifi-

cation to the network representation from a series to a model in the Load Flow routine would also be considered a desirable change.

One general recommendation that would greatly enhance the value of the program is to add some method of specifying how single phase branch currents are connected to three-phase systems. At many installations in the Air Force, the power distribution system will have several single phase branch circuits. Presently, single phase loads on branch circuits have to be simulated as three-phase loads or ignored when using the Load Flow routine. This kind of approximation could have an undesirable effect for accurate analysis of the system.

To further enhance the credibility of the PDSAP program, extensive testing using the IEEE Standard Test System and then a comparison with published results for these test systems is recommended. Some of the logic in the PDSAP program is based on published articles that used the IEEE standard systems (Ref 4:864), and a comparison of the results from different programs would be noteworthy.

Input Routines. Often errors on the line element data cards cause premature termination of the program. Development of a separate data scan program, using minimum computer memory space and processing time, is recommended. With the use of a separate input error checking routine, computer usage would be considerably more efficient than the present methods with error checking in the main program.

In the LINDATA routine, adding the capability to use all aluminum wire or cable would be a worthwhile addition. As more aluminum comes into use, the need for this change may become more urgent.

Also in the LINDATA routine, expanding the wire tables to lower voltages and smaller wire sizes is recommended. From data submitted to date, there appears a need for a computer program to analyze power distribution systems for individual buildings. As often only sketchy information is available on drawings, use of the LINDATA routine would be very valuable in these situations.

Load Flow Routine. As presently configured, the Load Flow routine has certain limitations. It is often difficult to satisfactorily simulate the systems with X/R ratios less than approximately 0.4. Using the fast decoupled method and trying to keep the program condensed as much as possible, the low X/R ratios can cause convergence problems when the 0.4 ratio is exceeded. This type limitation is most likely to be encountered with low voltage (less than 600 V) systems. If it is desired to extensively utilize the PDSAP on low voltage systems, this problem would have to be overcome since X/R ratios less than .4 are very common at lower voltages.

Short Circuit. In addition to the line outage routine previously recommended, a routine to change certain short circuit input data would be useful. In this regard, if fault impedances could be changed, similar to the load change capability in the Load Flow routine, the time required for additional computer runs could be minimized.

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Appendix A. User's Guide

This appendix contains a User's Guide for the PDSAP program. The guide is written so that it is a complete document that can be withdrawn and used separately with the PDSAP program.

Power Distribution System Analysis Program

(PDSAP)

User's Guide

1. Introduction

Purpose

The purpose of the Power Distribution System Analysis Program, PDSAP, is to provide analysis capability for various electrical distribution systems located on Air Force installations and to provide information to aid in the study and operation of these systems. The program has been developed so that it can easily be used to model electrical systems of the type normally operated and maintained by Base Civil Engineering personnel.

Capabilities and Limitations

The PDSAP program is capable of simulating systems with up to 250 buses and 500 lines. The program is formatted for the CDC CYBER 74 computer system and is written in FORTRAN. With necessary programing changes, it could be adapted to other computer systems of similar size. In addition to the lines, 250 transformers can be represented of which 50 may be Tap-Changing Under Load (TCUL) and 25 phase-shifting transformers. Series reactors and capacitors can also be modeled. Up to 50 of the 250 buses can be voltage controlled buses.

The program has 3 major functions: Calculate line impedance values; calculate power flows in lines throughout the system; and calculate fault currents for simulated faults at selected buses in the system.

Although the program is quite large and can simulate

almost any electrical system found with the Air Force, there are certain limitations that are necessary. These limitations are usually minor and will not adversely affect the overall accuracy of the analysis. The specific limitations are noted at appropriate locations in the following chapters. As presently configured, the program has no capability of transient stability analysis nor simulating line outages. Line outages can be simulated by alterations to the input data.

The following chapters of the guide, with the exception of the last two chapters, are entitled to represent the sections of the program: Program Control, Line Element Data, Load Flow Analysis and Short Circuit Analysis. It is suggested that the first two chapters be read in detail prior to attempting to use the program. Each chapter, with the exception of the last two, discusses input requirements and output products unique to that section of the program. Once the user has selected the desired functions in the control section, subsequent sections of little interest can be passed with a brief overview.

Input Data Requirements

The power system analysis program is designed to develop a computer simulation of a power system based in information usually found on a complete one-line system diagram. The program has the flexibility of using this information in almost any form normally found. Depending upon the desire of the user, some input data may be omitted if not using all

the major functions of the program. Information not available can often be approximated by the user. For some variables, preset values within the program can be used if actual values are unknown. Variables with the preset option will be so noted throughout the following chapters. However, for the best results, the more detailed the input information, the greater the accuracy of the result.

Input data for the program is entered by the use of the standard 80 column computer card. Coding of the data on standard coding forms such as AF Form 1531, Punch Card Transcript, is highly recommended before punching of the data cards is attempted. As is true with most computer data, accuracy in the coding is very important. As a general rule, after the coding forms have been prepared, a cross check should be made with the one-line diagram of other source data to insure correctness. Throughout the instructions, the various input requirements will be specified using one of 3 FORTRAN formats: F, I or R. The F format is used where real numbers, such as 875.53, may be used. The I format is used where an integer, such as 9, is required. With an integer format, no decimal points are allowed. No entry always implies an integer value of 0. Integers can be used in F formats, but care should be taken as the decimal point will be inserted automatically. An F5.2 format and an input value of 4839 will be used as 48.39 for example. For integers used with I or F formats, if the number is not right justified, or started in the right most column, zeros will be

added in the empty columns to the right to complete the format. For example, if the format was I3 and a 4 was placed in column 2, a value of 40, would be assumed by the program. Use of commas in large numbers is not permitted; 1,043 should be 1043 as an example.

The R format is an alphanumeric format where various combinations may be used as desired. For example, an R7 format could be Alpha 2. The program has several important control cards in each function. The cards are started with an R format and use a key word such as PGMCON. The purpose of the key word is to insure the control cards are properly identified and located in the program. The spelling and location of the key word on the control cards is essential and it is imperative that the data be entered in the columns specified for proper computation.

Output Data and Errors

The output data will vary in format and quantity depending on which of several options is selected by the user. In each of the following chapters, the output products are discussed for each major function of the program.

The PDSAP program contains a fairly comprehensive data checking and error detection routine. Should a problem be encountered with the input data or in computation, the program will output a message to identify the problem. Usage of the error messages in resolving problems is discussed in the next to last chapter of the guide.

Examples

The last chapter presents several examples showing the various input and output formats. These examples are necessarily brief due to space limitations, but can be used as a guide in modeling larger systems.

2. Control

Introduction

In the PDSAP program there are two types of control cards, FORTRAN and program. FORTRAN control cards are used to load the program into the computer's permanent file or to access the program if already on file. The FORTRAN control cards should be prepared by the person who will be submitting the information to the computer center. Program control cards determine the functions of the program to be used, output products and system parameters. Program control cards should be prepared by the person who is preparing the data for computation.

FORTRAN Control Cards

The PDSAP program exists as a source deck, or data card deck, consisting of some 3700 standard computer cards. The program must be loaded into the computer and a binary file created before data can be submitted for processing. To load the source deck, the following cards are required:

1. xx,T40,IO80,CM164000,STCSB. Txxxxxx,Name,Tel.Ext.
2. REQUEST,PDSAP,*PF.
3. MAP,PART.
4. FTN,OPT=2,B=PDSAP,R=3.
5. LOAD,PDSAP.
6. NOGO.
7. REWIND,PDSAP.
8. CATALOG,PDSAP,CY=xx,RP=xxx,ID=Txxxxxx,XR=xxxx.

9. *EOR
10. Source deck
11. *EOR
12. *EOF

For detailed information on FORTRAN cards, consult the User's Guide available at the computer terminal or see the FORTRAN Reference Manual. Alternative options are available on the FTN card as noted in the preceding references.

The following FORTRAN control cards are used when the source deck has been previously loaded, compiled and permanently filed in the computer.

1. xxx,Txxx,IOxx,CM164000,STCSB. Txxxxxx,Name,Tel.Ext.
2. ATTACH,PDSAP,CY=xx,ID=Txxxxxx.
3. PDSAP.
4. DISPOSE,TAPE1,PR=IBB.
5. DISPOSE,TAPE2,PR=IBB.
6. *EOR
7. Data Cards
8. *EOR
9. *EOF

The first Txxx is processing time requested. For impedance calculations and/or short circuit analysis, T50 is usually sufficient. For load flow analysis a larger Txx, up to T200 or more, may be required for time to obtain the desired convergence on a large system. IOxx is the amount of input/output time required. For programs of 50 buses or less, IO20 should be sufficient. Systems with more buses

may require IO50.

Other combinations of control cards are possible. For a one-time job, the source deck and data deck could be run at the same time, however this method might prove to be slightly more expensive and less efficient. The source deck is not designed to be repeatedly loaded and great care must be used not to get the deck out of sequence.

The program uses two output files, Tape 1 and Tape 2. Information printed on the tapes will be detailed in later chapters and illustrated with the example problems.

Program Control Cards

The program is designed to perform three separate functions as described in the introduction. The order and format of the program control cards is very important as all calculations will be affected by these values. Program control cards will be referred to as "control cards" throughout the following chapters and do not include the FORTRAN control cards previously discussed. The first three control cards title the system, select the functions desired and establish parameters to be used throughout the program. Figure A-1 will show the overall program card deck arrangement. This figure and the examples in the last chapter should be used to arrange the cards in proper order.

The first control card, which follows the first *EOR FORTRAN control card, is the Title card. This card can have 80 alphanumeric characters, in two groups of 40 columns each.

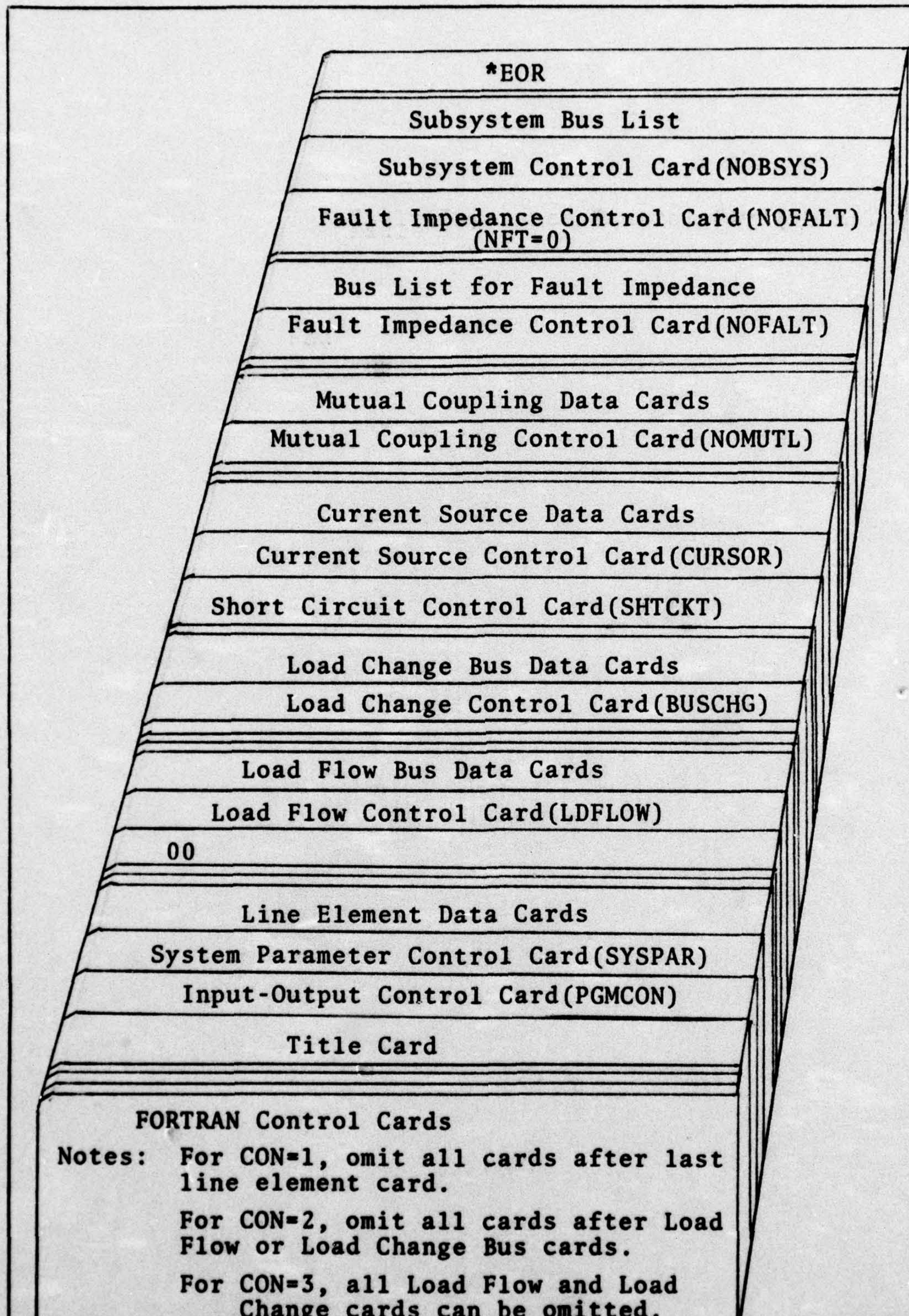

Fig. A-1. PDSAP Card Deck Structure

This card provides two "title" lines for the program. The first 40 columns will appear on one line and the second 40 columns on the following line.

The second control card is the Input-Output card. This card controls the selection of the program function, input format to be used, and output products produced. Four variables: CON, INP, OUT, and CHG are used on this card. The CON variable is for the function control, the INP variable is for line data input control, the OUT variable is for output selection, and the CHG variable is not used at present. Table A-I details the code values for the Input-Output card.

The third control card is the System Parameter card. This card is used to select the base KVA, frequency, temperature and earth resistivity. The program uses pre-selected values for any parameter not specified on this card. Table A-II specifies the variable location for the System Parameter card.

Fig. A-2 shows the location of the variables on the first three control cards. Examples of actual control cards are in the last chapter.

1... ...40	41... ...80
4R10	4R10
1st Line of Title	2nd Line of Title

Title Card

1......6	7-9	10-12	13-15	16-18	19... ...80
R6	I3	I3	I3	I3	
KYWD	CON	INP	OUT	CHG	

Input-Output Control Card

1 - 6	7-13	14-18	19-23	24-28	29... ...80
R6	F7.0	F5.0	F5.0	F5.0	
KYWD	BKVA	F	T	RH01	

System Parameter Control Card

Fig. A-2. Title, Input-Output, and System Parameter Cards

Table A-1

Input-Output Control Card Variables

Variable (Card Col)	Definition/Use
KYWD (1-6)	Keyword, use PGMCON.
CON (7-9)	Function selector. Choose 1, 2, 3, or 5. 1=Assemble line input data only. 2=Assemble line input data and run Load Flow analysis. 3=Assemble line input data and run Short Circuit analysis. 4=Not used at present. 5=Assemble line input data and run both Load Flow and Short Circuit analysis.
INP (10-12)	Input selector for line data. Choose 1 or 0. No entry implies 0. Use 1 when input impedances in ohms or per-unit. See chapter on line data.
OUT (13-15)	Output selector. Choose value from Table A-III for desired output lists. No entry implies 0.
CHG (16-18)	Not used at present, leave blank.

Table A-II

System Parameter Control Card Variables

Variable	Definition/Use
KYWD (1-6)	Keyword, use SYSPAR.
BKVA (7-13)	Base KVA. Use selected base. No entry implies 100,000 KVA. Base KVA range: 1 to 100,000 KVA.
F (14-18)	Frequency in hertz. No entry implies 60 hz.
T (19-23)	Temperature in degrees C. No entry implies 25 C.
RH01 (24-28)	Earth resistivity in meter-ohms. No entry implies 100 meter-ohm.

Table A-III

Codes for OUT Variable

Code	Definition
0	No outputs suppressed. Assembled line data printed in per-unit values.
1	No outputs suppressed. Assembled line data printed in ohms.
2	Suppress Tape 1 data. This includes all line data, input bus lists, input short circuit data.
3	Suppress assembled line data only. Sorted list of line data still printed.
4	Suppress sorted line data (G and B list). Assembled line data printed in per-unit values.
5	Suppress both assembled and sorted line data.
6	Suppress line flows in Load Flow function. Output bus data printed.
7	Suppress reordered bus list, input bus list printed.
8	Suppress assembled and sorted line data, reordered bus list and input bus list.
9	Suppress transformer output data. Line list and bus list printed.
10	Suppress all outputs except Load Flow bus summaries and short circuit fault summaries.
11	Start new page for each fault summary.
12	Suppress Short Circuit voltage and line current summaries.
13	Suppress Short Circuit voltage summaries.
14	Suppress Short Circuit voltage summaries and start new page for each fault summary.
15	Applies to LINDATA routine only. Input data is printed exactly as appears on data cards, program halts.

3. Line Element Data

Introduction

There are two line element routines available, LINEZ and LINDATA. The LINEZ routine should be used where input impedance values are in per-unit, ohms or a combination of the two. The LINDATA routine should be used where impedance values are unknown. The size, rating, length and other variables with LINDATA routine are used to calculate the correct impedances. The two routines cannot be used in the same system simulation. Therefore, the data for the line elements should be reviewed and the routine selected that will result in as little manual computation by the user as possible. As noted in the preceding chapter; on the Input-Output control card (PGMCON) a value of 1 for INP selects the LINEZ routine and a 0 selects LINDATA.

Both the LINEZ and LINDATA routines use several variables to compute the line impedance values which are then used by other functions of the program. Each data card is used to represent a line element. Line elements are aerial lines, underground cables, transformers, series capacitors, and series reactors. All line elements must be connected between two buses. Bus numbers must start with 1 and run consecutively until all buses are numbered. The location of the bus numbers is not significant, but some logical order will facilitate cross checking for errors and omissions. Bus locations should be chosen at points of interest and where line

elements change. Locations would normally be ends of lines, both sides of transformers, both sides of switches, and where loads are connected.

The line element data cards can be assembled in any order except the last data card which represents the ground or reference. This card should have a start bus (SB) and end bus (EB) of 0. No other entry is used on this card.

Neutral or ground wires in close proximity to phase conductors will have an effect on zero sequence impedance values. The presence of neutrals can be coded in both routines when simulating aerial conductors. The routines adjust the zero sequence impedance values to account for the presence of the neutrals.

Both routines use the same codes for line element identifiers (ID) and transformer windings (C). Codes for these variables are listed in Tables A-IV and A-V.

Table A-IV
ID Code Values

ID Code	Line Element Description
1	Copper, aerial
2	ACSR, aerial
3	Underground cable, aluminum conductor
4	Underground cable, copper conductor
5	Transformer, fixed up
6	Transformer, auto
7	Transformer, TCUL
8	Transformer, Phase-shifter
9	Series Capacitor
10	Series Reactor

Table A-V

Transformer Connection Codes

Type	Code	Winding Description (SB/EB)
Fixed or TCUL	1	Y/Y, Y/Y⏚, ⏚Y/Y, Y/Δ, Δ/Y
	2	Δ/Δ
	3	Y⏚/Y⏚
	4	⏚Y/Δ
	5	Δ/Y⏚
Auto	1	Y/Y (Not 3-ph core type)
	2	Y⏚/Y⏚ (Not 3-ph core type)
	3	Y⏚/Y⏚ (3-ph core type)
	4	Y⏚/Y⏚ two series windings (Not 3-ph core type)
	5	Y⏚/Y⏚ two series windings (3-ph core type)
Phase-Shifter	1	Series; Y/Y auto exciting (grounded or ungrounded neutral).
	2	Series; Y/Y auto exciting (grounded neutral, 3-ph core type).
	3	Series; Y/Y auto exciting (grounded neutral/tertiary).
	4	Series; Y/star exciting (grounded or ungrounded neutral).
	5	Series; Y/star exciting (grounded neutral, 3-ph core type).
	6	Series; Y/star exciting (grounded neutral, tertiary).
	7	Excited series.
	8	Star series; Δ/star exciting (grounded or ungrounded neutral).

LINEZ Routine

The LINEZ input routine, INP=1, is capable of accepting only values in per-unit or ohms for all line elements. Values for both positive and zero sequence, operating voltage, and bus connections are entered on each line element data card. If the zero sequence impedance is not specified, the program assumes a value for lines based on 3.5 times the positive sequence impedance for lines with neutrals. For transformers, capacitors, and reactors, the zero sequence impedance value is set equal to the positive sequence impedance value unless specified otherwise on the data card.

The format for the LINEZ line element data card is shown in Fig. A-3. The variables and the definitions for the LINEZ data card are given in Table A-VI.

LINDATA Routine

The LINDATA routine, INP=0, is designed to accept line element information that may be available when the impedance values are unknown. The conductor size, length, spacing and other information is used to calculate line impedances. Table A-VII shows the various sizes and strands of conductors that can be simulated in the program. The routine has the capability to use different size wire for phase conductors than that used for the neutral. If data on neutral conductors is not available, an approximation is made of 133,100 CM for ACSR neutrals and 105,500 CM for copper neutrals. KVA ratings, voltages, and winding information are used to

1-3	4-6	7-11	12-13	14	15-20	21-26	27-32	33-38	39-44
I3	I3	F5.0	I2	I1	F6.0	F6.0	F6.0	F6.0	F6.0
SB	EB	VP	ID	PH	L	ReZZ	ImZZ	ReZZ0	ImZZ0

45-48	49-53	54-58	59-63	64-65	66-67	68-73	74-78	79	80
F4.0	F5.0	F5.0	F5.0	I2	I2	F6.0	F6.0	I1	
PHI	TPI	TMNN	TMXX	C	IUNIT	ReZN	ImZN	CH	

Fig. A-3. Line Element Card Format for LINEZ Routine

Table A-VI

Line Element Variables for LINEZ Routine

Variable (Card Column)	Definition/Use
SB (1-3)	Start bus; bus number to which one end of line element is connected. Also called "from bus." Must be tapping end of a TCUL element.
EB (4-6)	End bus; bus number of other end of line element. Also called "to bus."
VP (7-11)	For conductors, capacitors, and reactors: Voltage (KV) line-to-line if 3-ph or line to-neutral if 1-ph. For Transformers: Voltage (KV) high side rating.
ID (12-13)	Line element identifier; Choose code from Table A-IV.
PH (14)	Phase. Choose 1 or 3.

Table A-VI (Cont'd)

Variable (Card Column)	Definition/Use
L (15-20)	For conductors: Length in feet. For other elements: KVA rating in KVA.
ZZ (21-26) (27-32)	Positive sequence impedance. Complex, enter as two numbers in ohms or per-unit values.
ZZ0 (33-38) (39-44)	Zero sequence impedance. Complex, enter as two numbers. If unknown, leave blank; program will assume values based on positive sequence values.
PHI (45-53)	Phase angle (degrees). For phase-shifter only. All other elements: Leave blank.
TPI (49-53)	For conductors: Enter 1 for zero sequence adjustment for ground or neutrals, otherwise skip. For transformers: Initial tap setting in per unit. No entry implies 1.0. For other elements: leave blank.
TMNN (54-58)	For TCUL transformer, minimum tap limit in per unit. No entry implies .9. For other elements: Leave blank.
TMXX (59-63)	For TCUL transformer, maximum tap limit in per unit. No entry implies 1.1. For other elements: Leave blank.
C (64-65)	For conductors, capacitors and reactors: Leave blank. For transformers: Choose connection code from Table A-V.
IUNIT (66-67)	Impedance units identifier. For all elements: Blank or 0 for impedance values in ohms. 1 implies per-unit on system base KVA. For transformers capacitors and reactors: 2 implies per-unit on element base KVA.
ZN (68-73) (74-78)	For conductors, capacitors and reactors: Leave blank. For transformers, neutral impedance if other than zero. Use ohms or per-unit values.
CH (79)	Not used presently, leave blank.

Table A-VII

Wire Sizes

Circular Mils (CM)	A.W.G.	Comments
1,000,000	-	If UG, 3-ph only
750,000	-	If UG, 3-ph only
500,000	-	If UG, 3-ph only
350,000	-	
300,000	-	
250,000	-	
211,600	4/0	
167,800	3/0	
133,100	2/0	
105,500	1/0	
83,690	1	
66,370	2	
41,740	4	
26,250	6	
16,510	8	

Number of Strands:

Copper: 37,19,12,7,3,1,or 0

ACSR (Aluminum part): 54,30,26,6,or 0

1-3	4-6	7-11	12-13	14-19	20-21	22	23-29	30-31	32-35	36-41
I3	I3	F5.0	I2	F6.0	I2	I1	F7.0	I2	F4.0	F6.0
SB	EB	VP	ID	L	C	PH	S	STR	DM	SG

42-46	47-51	52-56	57-61	62-66	67	68-73	74-79	80
F5.0	F5.0	F5.0	F5.0	F5.0	I1	F6.0	F6.0	I1
STRG	DMCG	DMGG	ReZN	ImZN	NG	ReZ	ImZ	CH

NOTE: For elements other than conductors, use Fig. A-5.

Fig. A-4. Conductor Data Card Format for LINDATA Routine.

1-3	4-6	7-11	12-13	14-19	20-21	22	23-29	30-31	32-35	36-41
I3	I3	F5.0	I2	F6.0	I2	I1	F7.0	I2	F4.0	F6.0
SB	EB	VP	ID	L	C	PH	S	STR	PHI	VS

42-46	47-51	52-56	57-61	62-66	67	68-73	74-79	80
F5.0	F5.0	F5.0	F5.0	F5.0	I1	F6.0	F6.0	I1
TMNN	TMXX	TPI	ReZN	ImZN	TC	ReZ	ImZ	CH

NOTE: For conductors use Fig. A-4.

Fig. A-5. Data Card Format for LINDATA Routine.

Table A-VIII

Line Element Variables for LINDATA Routine

Variable (Card Column)	Definition/Use
SB (1-3)	Start bus: Bus number to which one end of line element is connected. Also called "from bus." Must be taping end of a TCUL element.
EB (4-6)	End bus: Bus number of other end of line element. Also called "to bus."
VP (7-11)	For conductors: Voltage (KV) line-to-line if 3 ph or line-to-neutral if 1 ph. For transformers: Voltage (KV) high side.
ID (12-13)	Line element identifier: Choose code from Table A-IV.
L (14-19)	For conductors: Length in feet. For other elements: Leave blank.
C (20-21)	Connection code. For conductors: Leave blank. For transformers: Choose code from Table A-V.
PH (22)	Phase. Choose 1 or 3.
S (23-29)	For conductors: Diameter in circular mils (CM). See Table A-VII for choices on wire sizes. For transformers and others: Rating in KVA.
STR (30-31)	For conductors: Number of strands. See Table A-VII for choices. If unknown, leave blank. For other elements: Leave blank.
DM or PHI (32-35)	For conductors: Equivalent spacing in feet. If unknown, leave blank and value assumed as 4.69 for 25 KV or less, 12.57 for above 25 KV. For phase-shifter transformers: Phase angle. For other elements: Leave blank.
SG or VS (36-41)	For conductors: Size of neutral in circular mils. If none or unknown, leave blank. For transformers: Secondary voltage in KV. For other elements: Leave blank.

Table A-VIII (Cont'd)

Variable (Card Column)	Definition/Use
STRG or TMNN (42-46)	For conductors: Number of strands in neutral, if known. If unknown or none, leave blank. For transformers: Minimum tap setting for TCUL in per-unit. If blank, assumes .9. For other elements: Leave blank.
DMCG or TMXX (47-51)	For conductors: Equivalent spacing between conductors and neutral (ft). If unknown or none, leave blank. For transformers: Maximum tap setting for TCUL in per-unit. If blank, assumes 1.1. For other elements: Leave blank.
DMGG or TPI (52-56)	For conductors: Equivalent spacing between neutrals if more than one. If unknown or none, leave blank. For transformers: Initial tap setting in per-unit. If blank, assumes 1.0. For other elements: Leave blank.
ZN (57-61) (62-66)	For conductors: Leave blank. For transformers: Neutral impedance, if other than zero, in ohms. Enter as real and imaginary. For other elements: Leave blank.
NG or TC (67)	For conductors: Number of neutral of ground wires. For other elements: Positive sequence impedance selector. 0 will use program calculated value. 1 will use value specified by Z variable as ohms. 2 will use value specified by Z variable as per-unit on base KVA of line element.
Z (68-73) (74-79)	For conductors: Leave blank. For transformers: Positive sequence impedance in ohms or per-unit. Complex value, enter as two numbers in ohms or per-unit. If unknown, insure TC variable is 0.
CH (80)	Not used presently, leave blank.

determine the impedance values for transformers and other elements.

Two formats are used for the LINDATA routine, one for conductors and the other for transformers, series capacitors and series reactors. Zero sequence impedance values are calculated in the routine based on the positive sequence values. Fig. A-4 shows the format for the conductors and Fig. A-5 shows the format for other elements. Variables for both formats are defined in Table A-VIII.

Limitations

Both LINEZ and LINDATA routines have certain limitations. Due to the algorithm used with the Load Flow routine, input line elements usually cannot have an X/R ratio less than .4, but this restriction can be waivered if only using the Short Circuit routine. With the LINEZ routine, the data can be checked before being entered on the data cards. With the LINDATA routine it may be necessary to run the program, using CON=1 on the Input-Output control card, to calculate impedance values in order to determine the X/R ratio.

The line element routines do not have the capability to simulate a three-winding transformer except those used as phase shifting transformers can be simulated if only two windings are connected to the system. The problem of simulating a three-winding transformer can be resolved by modeling the transformer as three separate two-winding transformers as described by the following procedure:

1. Identify the impedance of the three windings; Hi (ZH), Med (ZM), and Lo (ZL). Note winding information such as Hi/Med is (Wye-Delta).

2. Using the impedance values given for Zhl, Zmh, and Zml, calculate vales for ZH, ZM, and ZL as shown. Zhl, Zml, Zmh are the given impedance values for Hi/Lo, Med/Lo and Med/Hi windings respectively.

$$ZH = \frac{Zhl+Zmh-Zml}{2} \tag{8}$$

$$ZL = \frac{Zml+Zhl-Zmh}{2} \tag{9}$$

$$ZM = \frac{Zmh+Zml-Zhl}{2} \tag{10}$$

3. Use a wye configuration for the three impedance values, ZH, ZL, and ZM as shown in Fig. A-6. Use bus numbers, such as 1, 2 and 3 for each end of the wye and use N for the common middle point.

4. Convert the wye configuration to an equivalent delta by any standard method (Ref 6:155-156 as follows:

$$Z_{12} = \frac{(ZH)(ZM)+(ZM)(ZL)+(ZH)(ZL)}{ZL} \tag{11}$$

$$Z_{13} = \frac{(ZH)(ZM)+(ZM)(ZL)+(ZH)(ZL)}{ZM} \tag{12}$$

$$Z_{23} = \frac{(ZH)(ZM)+(ZM)(ZL)+(ZH)(ZL)}{ZH} \tag{13}$$

5. Using the winding characteristics asso-

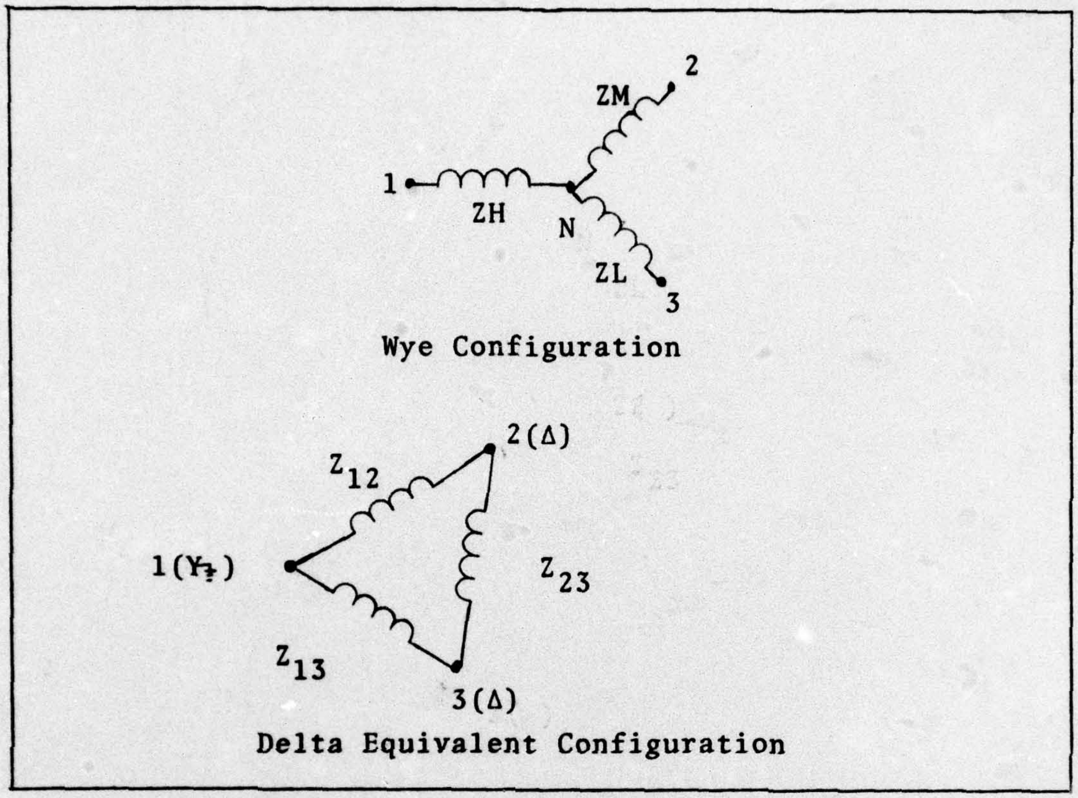

Fig. A-6 Delta Equivalent Three-Winding Transformer

ciated with each bus number, such as Hi(1)(wye) or Med(2)(delta), assign appropriate winding characteristics to each bus as shown in Fig. A-6. Winding characteristics should be chosen from the given information for the transformer.

6. Code the input data for the program using the equivalent delta configuration as three two-winding transformers with connection codes as appropriate. Use the highest voltage rating of the three-winding transformer as the high side voltage on the three two-winding transformers.

7. Unless other information is given, let the

LINEZ or LINDATA routine calculate the zero sequence impedance values.

Output

Output from both the LINEZ and LINDATA routines is similar. The first item is the program title and printout designation, Tape 1 or Tape 2. The second item is the system title chosen by the user. The third item is the program control constants as chosen on the Input-Output control card. A -0 indicates no entry was made and is the same as 0. The fourth item is the program parameter constants as coded on the System Parameter control card. These four items appear on both Tape 1 and Tape 2 printouts.

Next, on the Tape 1 printout only, appears the LINEZ or LINDATA header format stating the assembled line element data is in per-unit or ohms. The entries in this listing are in the same order as the line data input cards. Following the assembled line input data is the sorted line data list. The list is sorted by ascending line numbers and lists the start and end bus, the G (Conductance) and B (Suspectance) values, plus the zero sequence impedance values. If either the Load Flow or the Short Circuit routine is utilized, other entries appear between the assembled line list and the sorted line list.

The output data from the LINEZ and LINDATA routines is controlled by the OUT variable on the Input-Output control card. A review of Table A-III indicates output content is on Tape 1 and Tape 2 when a value of OUT other than 0 is selected.

4. Load Flow Analysis

Introduction

The Load Flow function of the program is used to calculate power flow throughout the system. Inputs required, in addition to the line element data, are the loads and generating sources in the system. Output is the power distribution throughout the system which shows the load requirements at each bus, line flows, and the amount of power imbalance that is accounted for on the slack bus.

Inputs

The first card in the Load Flow function is the Load Flow control card, LDFLOW, which is used to select the tolerance desired for the comparison between the calculated and specified power requirements on each bus. The tolerances, expressed in per-unit, are labeled PTOL and QTOL, for real and reactive power. Accuracies to about 1 KVA are possible. The tolerances should be consistent with the magnitude of the loads on the system. On the same card, the number of iterations that will be permitted to reach the selected tolerance is also specified as ITR1 and ITR2. ITR1 is the iteration counter for PTOL and ITR2 the counter for QTOL. One other item, NLC, is also specified on the LDFLOW control card. This variable is used to select the load change routine. Any number, other than zero, will select the number of times the basic program is to be modified by load changes within the system and a new load flow result calculated.

The format and variable description for the Load Flow control card are found in Table A-IX and Fig. A-7.

1-6	7-10	11-14	15-21	22-28	29-31....	80
R6	I4	I4	F7.5	F7.5	I3	
KYWD	ITR1	ITR2	PTOL	QTOL	NLC	

Fig. A-7. Load Flow Control Card

Table A-IX

Load Flow Control Card Variables

Variable (Card Column)	Description/Use
KYWD (1-6)	Key word. Always use LDFLOW.
ITR1 (7-10)	Maximum number of iterations to reach specified tolerance in PTOL. Choose number between 1 and 9999.
ITR2 (11-14)	Maximum number of iterations to reach specified tolerance in QTOL. Choose number between 1 and 9999.
PTOL (15-21)	Tolerance, difference between P specified and P calculated in per-unit. Usually between .1 and .0001.
QTOL (22-28)	Tolerance, difference between Q specified and Q calculated in per-unit. Usually between .1 and .0001.
NLC (29-31)	Number of times load buses will be changed and load flows re-calculated. Choose number between 0 and 999.

Following the Load Flow control card, LDFLOW, are the bus data cards. One bus data card is required for each bus. If the bus does not have a load or a source, the P and Q values may be left blank, but the bus number and type are required. If more than one load is located at a bus, the loads must be combined as only one bus card is permitted for each bus. Power flowing into a bus, such as from a generator, is considered positive. Power flowing out of a bus, such as to a load, is listed as negative values. The format and definition of variables used for the Load Flow Bus Data cards are shown in Fig. A-8 and Table A-X.

Three types of buses are used as shown in Table A-X. The most numerous are the load buses, or Type 1 buses. Type 2 buses, voltage controlled buses, are normally for sources where the voltage should be held constant. The program assumes that whatever reactive power required to do this will be available as long as it does not exceed the QMIN or QMAX limits selected. If the limits are exceeded, the voltage will be adjusted and a message printed with the results noting the voltage has not been held constant. The slack bus, Type 3, is to absorb all overages and shortages throughout the system. There must be one, and only one, slack bus for each system. The voltage must be specified for the slack bus but not the P and Q values.

The load change feature changes any number of loads in the simulated system and then calculates a revised load flow system summary. The same PTOL, QTOL, ITR1, and ITR2 will be

1-2	3-5	6-15	16-20	21-25	26-35	36-45	46-55	56-65	66..80
I2	I3	R10	F5.0	F5.0	F10.0	F10.0	F10.0	F10.0	
IDB	IBUS	BUSNME	V	ANG	P	Q	QMIN	QMAX	

Fig. A-8. Load Flow Bus Card Format

Table A-X

Load Flow Bus Card Variables

Variable (Card Column)	Description/Use
IDB (1-2)	Bus type. Choose 1,2,or 3. 1 Load bus. Specify P and Q. 2 Voltage Control Bus. Specify P and V. 3 Slack Bus. Specify V and ANG. (Only one type 3 bus allowed and required)
IBUS (3-5)	Bus number. Use consecutive numbers between 1 and 250, same as used for lines.
BUSNME (6-15)	Name of bus, up to 10 numbers and/or letters. May leave blank if desired.
V (16-20)	Bus voltage magnitude, in per-unit. No entry implies 1.0.
ANG (21-25)	Bus voltage angle, in degrees. No entry implies 0 degrees.
P (26-35)	Bus real power specified in KVA. Injected power is positive, loads are negative.
Q (36-45)	Bus reactive power specified in KVAR. Injected is positive, loads are negative.
QMIN (46-55)	Minimum reactive power limit. Specified for type 2 buses in KVAR. Other types, 0.
QMAX (56-65)	Maximum reactive power limit. Specified for type 2 buses in KVAR. Other types, 0 or leave blank.

used. The line data used is also the same as for the initial calculation. To vary the loads, select the value of NLC on the LDFLOW control card to indicate how many times the system will be modified and re-calculated. Next, following the last bus data card, add the load change control card, BUSCHG, with a value for NC representing the number of buses to be modified with this change. Following the load change control card, add the bus cards as changed. The bus cards must only be Type 1 and use the same bus number as the bus to be replaced. Fig. A-9 illustrates the load change control card, BUSCHG. Bus data cards should be in format as shown in Fig. A-8. If more than one change is selected, NLC greater than 1, additional BUSCHG control cards and bus data cards are added as required.

If several load changes are used or the system is very large, an increase in the computation time, TXXX, as allowed by the FORTRAN Control card may be required.

```
1-6 7-9 10....                                   ....80
 R6  I3
KYWD NC
```

Variable (Card Column	Definition/Use
KYWD (1-6)	Key word, use BUSCHG.
NC (7-9)	Number of buses to be changed. Follow with same number of bus data cards.

Fig. A-9. Load Change Control Card

Limitations

As noted previously, only one bus card is allowed per bus. Therefore, if both loads and sources are present at the same bus, only the net difference can be entered on the bus card.

The program uses an iterative routine to balance the system between calculated and specified power at each bus. If the number of buses is large, a larger time on the first FORTRAN control card, TXXX, may be required for the desired tolerance.

Convergence to any selected tolerance is usually obtainable unless the X/R ratio is .4 or less. When the X/R ratio approaches .4, convergence becomes more difficult and sometimes impossible regardless of the tolerance selected. When the specified tolerance is not reached with the number of iterations allowed, the output will not show line flows, but will show the DLP and DLQ values. The DLP and DLQ values are the difference between the specified and calculated power at each bus when the iteration limit was reached. Load changes will not be processed when convergence to the selected tolerance has not been obtained.

There is no way of assigning a single phase load to a particular phase in a three-phase system. All loads are considered as balanced between phases.

Output

The output from the Load Flow routine is varied by the

OUT value selected on the Input-Output control card, PGMCON. If an OUT value of 0 is selected, all tables are printed. On Tape 1 printout appears an input bus list, showing the input load values for each bus and the type of bus. On Tape 2 printout appears the output bus data showing the calculated loads for each bus, the number of iterations required for convergence, the line flow power between all buses, and the slack bus power. If the load change routine is used, on the Tape 2 printout appears the number of the load change, the new bus data being added, and the re-calculated load flow result based on the modified system. All values are in per-unit notation and should be multiplied by the appropriate base for actual KW and KVA values.

5. Short Circuit Analysis

Introduction

The third function of the PDSAP program is the Short Circuit Analysis routine. The short circuit routine selectively simulates faults of various types at each bus and then examines the other buses and lines in the system to show fault currents available at these locations. The types of faults that can be simulated are three-phase, phase-ground, phase-phase, and phase-phase-ground.

Input

The first card in the Short Circuit routine is the Short Circuit control card, SHTCKT. On this card are entered 2 values, ISYS and SCOP. ISYS determines the network configuration for the short circuit study. The short circuit study can be run on any system up to 500 lines and 250 buses. However, simulated faults can only be calculated on 50 bus segments or less. ISYS indicates the number of bus groups to be analyzed. Each group can have from 1 to 50 buses and one bus may appear in more than one group. It is important to note, that although only 50 buses are shown, the entire system is used in the fault simulation. Changing the bus numbers in the subsystem does not in any way alter the system configuration. If changes in line connections are desired, the line element cards must be changed and the program re-run. The SCOP variable is used to select the type of fault conditions to be used. A blank implies a value

of 0. For most occasions, values of 0 or 2 should be used for SCOP. Table A-XI and Fig. A-10 illustrate the format and variable codes for the Short Circuit Control card, SHTCKT.

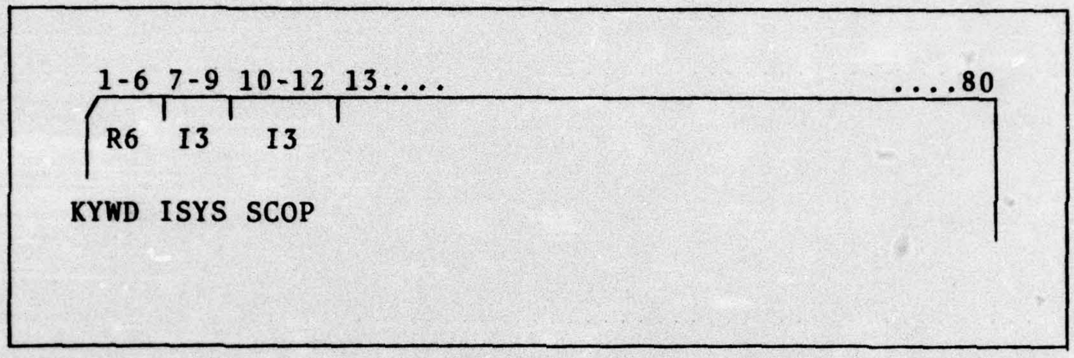

Fig. A-10. Short Circuit Control Card

Table A-XI

Short Circuit Control Card Variables

Variable (Card Column)	Definition/Use
KYWD (1-6)	Key word, use SHTCKT.
ISYS (7-9)	Number of subsystems to be used. If 0 or blank, all buses will be faulted in groups of 50.
SCOP (10-12)	Type of short circuit analysis. Choose 0,1,2, or 3. 0=All fault types used (3 Ph-Gnd, Ph-Gnd, Ph-Ph, Ph-Ph-Gnd). Bus Voltages are set to 1.0 per-unit. 1=Same as 0 except voltages are result of Load Flow routine. 2=Only Ph-Gnd and 3 Ph-Gnd faults used with bus voltages at 1.0 per unit. 3=Same as 2, except bus voltages are result of Load Flow routine.

The second card read by the Short Circuit routine is the Current Source Control card, CURSOR. This card specifies the number of buses that will contribute short circuit current to the system. Current sources will normally include the system source and large loads such as motors. It should include anything that would contribute current into the system in the event of a fault. If no current sources are present, the value on the CURSOR card may be 0 or blank. If there are no current sources, there must be at least one path to ground, or reference, through a transformer or other line element in the system being simulated. The last line element card is not considered part of the system although the SB and EB are 0. Fig. A-11 and Table A-XII show the format for current source control card.

Following the Current Source Control card are the Current Source Data cards. The variables on the Current Source Data cards are shown in Fig. A-12 and defined in Table A-XIII. The fault current, both FA3 and FA1, should normally have a large negative imaginary part based on the assumption of a positive reactance value for the source being simulated. If the data available for the system does not list short circuit current for the source, it may be calculated by knowing two of the following: KVA, voltage, or impedance of the source. Table A-XIV lists equations to use to find the short circuit current. The fault impedance, ZF, is any additional impedance, other than source impedance, prior to entering the system at the designated bus. Likewise, the neutral impe-

1-6	7-9	10....	80
R6	I3		
KYWD	IREF		

Fig. A-11. Current Source Control Card

Table A-XII

Current Source Control Card Variables

Variable (Card Column)	Definition/Use
KYWD (1-6)	Key word, use CURSOR.
IREF (7-9)	Number of current source data cards. If none, leave blank; but system then must have at least one path to ground through a transformer.

1-3	4-5	6-14	15-23	24-32	33-41	42-50
I3	I2	F9.2	F9.2	F9.2	F9.2	F9.2
IBF	BLK	ReVN	ImVN	ReFA3	ImFA3	ReFA1

51-59	60-64	65-69	70-74	75-79	80
F9.2	F5.1	F5.1	F5.1	F5.1	
ImFA1	ReZF	ImZF	ReZG	ImZG	

Fig. A-12. Current Source Data Card

Table A-XIII

Current Source Data Card Variables

Variable (Card Column)	Definition/Use
IBF (1-3)	Bus number of current source. Same as used for line elements.
BLK (4-5)	Not used. Leave blank.
VN (6-14) (15-23)	Voltage (KV) line-to-neutral as to a complex number. Usually all real.
FA3 (24-32) (33-41)	Short circuit input current (amps) as complex number. Usually all negative imaginary.
FA1 (42-50) (51-59)	Short circuit input current (amps) for Ph-Gnd fault. Usually all negative imaginary.
ZF (60-64) (65-69)	Fault impedance (ohms) as a complex number. Should be in addition to values used to calculate FA3 or FA1. Usually none.
ZG (70-74) (75-79)	Neutral impedance (ohms) as complex number. If any, should be in addition to values used to calculate FA3 or FA1.

Table A-XIV

Current Source Equations

Three Phase	Single Phase or Per-Unit
$I = KVA/V_{LL}\sqrt{3}$	$I = KVA/V$
$I = V_{LL}/Z\sqrt{3}$	$I = V/Z$
$I^2 = KVA/3Z$	$I^2 = KVA/Z$

Voltage values in KV or per-unit. Impedance values in ohms or per-unit.

dance, ZG, is any impedance, other than zero, between the source and the reference or ground.

Following the current Source Data cards is the Mutual Coupling Control card, NOMUTL. This card indicates the number of mutually coupled lines in the system being simulated. The routine has the capacity to simulate up to 25 mutually coupled lines. If there are no mutually coupled lines, the value on the card should be 0 or blank. Fig. A-13 illustrates the format for the Mutual Coupling Control card. When mutual coupling is present, following the Mutual Coupling Control card will be the Mutual Coupling Data cards. These cards should have the format as illustrated in Fig. A-13 and defined in Table A-XV.

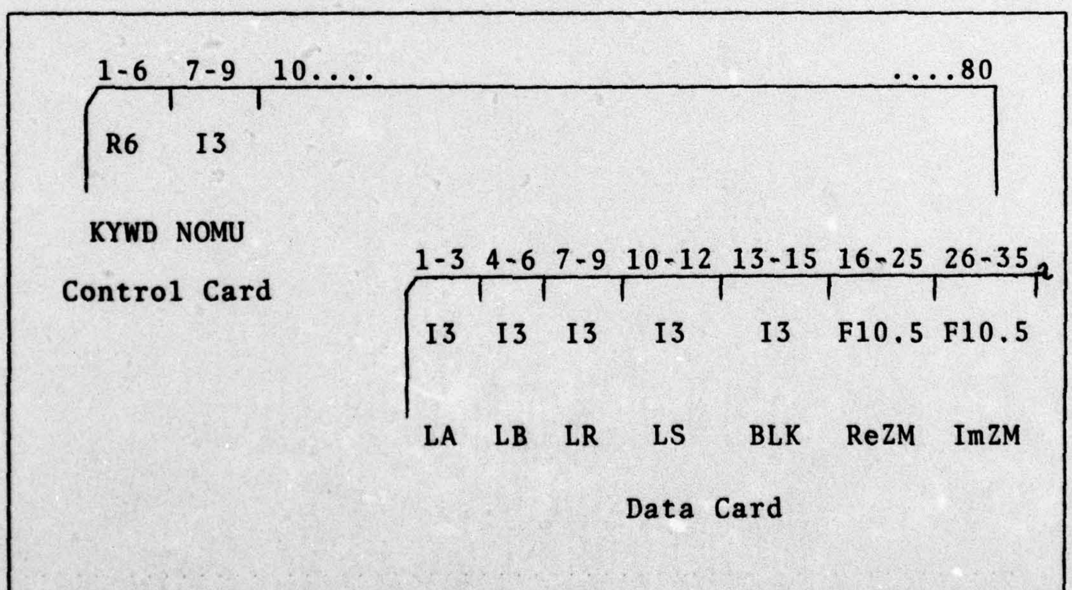

Fig. A-13. Mutual Coupling Control and Data Cards

Table A-XV

Mutual Coupling Variables

Variable (Card Column)	Definition/Use
KYWD (1-6)	Key word, use NOMUTL.
NOMU (7-9)	Number of mutually coupled lines. Same number of data cards should follow. If none, leave blank or enter 0.
LA (1-3)	Start bus of mutually coupled line. Use same numbers as in line element data.
LB (4-6)	End bus of mutually coupled line.
LR (7-9)	Start bus of line to which coupled.
LS (10-12)	End bus of line to which coupled.
BLK (13-135)	Not used, leave blank.
ZM (16-25) (26-35)	Mutual impedance between two lines in per-unit, complex.

After the mutual coupling cards are the fault impedance cards. The first fault impedance card is a Fault Impedance Control card, NOFALT. This card specifies the voltage, phase and fault impedance for a series of buses. Fault impedance, ZF, is the value of impedance between the fault and ground. Usually this is zero or some real value in ohms. If the fault impedance is assumed to be zero for the entire system, only one Fault Impedance Control card is required.

If there is more than one fault impedance value or different phases and voltages for the same value, additional Fault Impedance Control cards are needed. Fig. A-14 illustrates the format for the Fault Impedance Control card, and Table A-XVI lists the definition of the variables. With each Fault Impedance Control card that specifies an impedance other than zero, a bus list must immediately follow indicating to what buses the fault impedance applies. Fig. A-14 illustrates the bus list format and Table A-XVII the variables. The last card in this group must be a Fault Impedance Control card with NFT of 0.

The last group of cards in the Short Circuit routine are the subsystem cards. The Subsystem Control Card, NOBSYS, specifies the number of buses in the subsystem as shown in Fig. A-16 with the variables defined in Table A-XVIII. Up to 50 buses can be in any one subsystem. The bus numbers are listed on a bus list following the NOBSYS card. Fig. A-15 illustrates the format for the bus list. If there is more than one subsystem, ISYS greater than 1, then additional NOBSYS cards and bus lists are used. It is important to insure the number of NOBSYS cards equals the ISYS value on the Short Circuit Control card.

The use of the subsystem bus list should be considered carefully. When working with large systems, over 50 buses, and line currents in particular lines are of interest, the subsystem bus list should be used. When using the automatic feature (ISYS=0), there is no assurance that buses for lines

1-6	7-9	10-15	16-21	22-24	25-30	31.... 80
R6	I3	F6.0	F6.0	I3	F6.0	
KYWD	NFT	ReZF	ImZF	PH	VP	

Fig. A-14. Fault Impedance Control Card

Table A-XVI

Fault Impedance Control Card Variables

Variables (Card Column)	Definition/Use
KYWD (1-6)	Key word, use NOFALT.
NFT (7-9)	Number of buses to which fault impedance applies. If none, leave blank. Last NOFALT card must have NFT=0.
ZF (10-15) (16-21)	Fault impedance in ohms, complex. If any, usually all real.
PH (22-24)	Phase. Choose 1 or 3. All buses in group must have same phase.
VP (25-30)	Voltage (KV). Line-to-line if 3-Ph. Line-to-neutral if single phase. All buses in group must have the same voltage.

1-3	4-6	7-9	10-12	13....	75	76-78	79-80
I3	I3	I3	I3			I3	I2
IFB	IFB	IFB	IFB			IFB	BL

Fig. A-15. Bus List Format for Fault Impedance and Subsystem Buses.

Table A-XVII

Bus List Card Variables

Variables (Card Column)	Definition
IFB (1-3) (4-6) etc.	Bus numbers to which fault impedance or subsystem applies. Numbers should be in increasing order. Skip numbers to which does not apply.
BL (79-80)	Leave blank. If more than 26 buses in list, continue on a following card.

1-6	7-9	10....	80
R6	I3		
KYWD	NBS		

Fig. A-16. Subsystem Control Card

Table A-XVIII

Subsystem Control Card Variables

Variables (Card Column)	Definition/Use
KYWD (1-6)	Key word, use NOBSYS.
NBS (7-9)	Number of buses in subsystem list. Choose number between 1 and 50. List bus numbers on following card.

of interest will be in the same group if the system is large. For the line current to be printed, both the start (SB) and end bus (EB) of the line must be in the same group.

Limitations

There is no way to control to what phase of a three phase system a single phase branch circuit will be attached. A single phase circuit is always assumed to be attached to Ph-A. For better accuracy in short circuit studies, it may be beneficial to simulate the three-phase and single phase parts of the system separately.

Output

The output of the Short Circuit routine is controlled by the OUT variable on the Input-Output Control card and by the SCOP variable on the Short Circuit Control card. When both OUT and SCOP are 0, maximum information will be printed.

The Tape 1 printout shows the Short Circuit Input Data.

This includes the current sources, fault impedance and mutual coupling information.

Tape 2 printout shows the Fault Summary for each bus in the selected subsystem. The complete summary includes the three-phase, phase-ground, phase-phase, and phase-phase-ground fault currents and X/R ratios. An R for the X/R ratio indicates that no ratio could be formed as one value was 0. If any value appears as ****, this indicates the calculated value has exceeded the allowed space for the number. For the current magnitudes and X/R ratios, 999 per-unit is the limit.

Also as part of the Fault Summary are printed the phase voltages for the various types of faults. For faults between phases, the routine assumes the fault is between phases B and C. For the three-phase and phase-to-ground faults, the bus voltages for all buses in the subsystem will be listed. Likewise, line currents for three-phase and phase-to-ground will be listed for any lines connecting buses in the subsystem. If the fault current on a specific line is desired, both the start and end buses must be included in the subsystem list.

The magnitude of the fault current will be greatly influenced by the location and size of current sources, transformer connections, and impedance values for conductors. A small error in any one of the foregoing, could make a significant difference in the fault currents.

When the faulted bus is single phase, even if part of a

three-phase system, only the phase-to-ground information will be printed. Again, note that all values are in per-unit and should be converted to amps, ohms or volts by using the appropriate base values.

6. Trouble Shooting

The PDSAP program has numerous routines designed to detect errors with input data and errors that occur with calculations. When there is an error, usually it will appear as either a program error or a FORTRAN error.

For program errors, a statement will appear with the output data stating that the program has terminated for a particular reason. Usually there is enough information given to locate the input data card causing the problem. Program errors can usually be grouped into those caused by data cards and those caused by program control cards. When trouble develops, first check the deck structure as shown in Fig. A-1 for proper sequence of control cards and data cards.

Errors on data cards are usually caused by data not in the proper columns or improper coding. Both are very common errors and can be held to a minimum by careful checking of the data after the cards have been punched. Sometimes values entered for impedance, wire size or other parameters are non-standard and may cause problems. When this type of error occurs, the best solution is to change the variable causing the problem to a standard size or value. Also, impedance values of several hundred ohms may be too large for some operations. This can be corrected by adding additional buses to lower the values.

Other program errors can result from insufficient data being supplied. In some cases, values will be assumed for sizes, impedance or other variables when the input is omitted.

However, in other cases no entry results in a zero value which will halt the program. The error messages should help to identify the variable causing the problem.

A third situation that may cause an error is improper format being used. This is the result of a decimal point being omitted or an error in placing the data in the proper columns. This type of error may or may not halt the program. It is advisable to at least once check the printout of the assembled input line data to verify that no mistakes have occurred even if the program has run successfully.

When the error is a FORTRAN error, no output is produced except the day file which contains the FORTRAN control card information and the FORTRAN error. FORTRAN errors are not as easy to detect or correct as program errors.

Two common mistakes are to omit necessary data cards or to mis-count data cards. In several instances the number of data cards must match a variable designated on a preceding control card. This is true with the Load Change Control cards, BUSCHG, and the Current Source Control cards, CURSOR. In the Load Flow routine, the bus data cards must be the same number as the number of buses used in the line element program. When the number of data cards is less than required, or data cards are missing, the most frequent result is the FORTRAN error, "Illegal data in the field." When this type of error occurs, it means that the card with the data listed above the error statement is not compatible with the input format required. For this type of error, first check the

card for proper format and location. Perhaps a line element card got in the bus card group. Also check for missing control cards or missing data cards.

Another method of finding the cause of the FORTRAN error, "Illegal data in the field" is to look for the line numbers of the routines that were being used when the error occurred. This information will be just below the error statement. Fig. A-17 has an example of this type of error. By checking the line number with the same line number in a listing of the program, it is often easy to see why the error occurred.

One FORTRAN error that is almost impossible to locate is a mode error. A mode error usually occurs when division by zero is attempted in the program. For resolution of mode errors or other FORTRAN errors, one of the following methods may prove successful.

Try each function separately. Start by running input data only with either the LINEZ or LINDATA routines. Then add either the Load Flow or Short Circuit functions. This should determine which program function is causing the error. Carefully review the input data that is used by the program and compare it with the formats in the preceding chapters.

A second method that may prove useful if the system is quite large is to divide the system into smaller parts. If the program will work with 10 buses, add more until the problem is encountered. Look for abnormal sizes or mistakes in

```
S
Q
1         $$$$$$$$  $$      $$  $$$$$$    $$$$$$$    $$$$$$$    $$$$$$
             $$     $$      $$  $$    $$  $$     $$  $$     $$  $$     $$
             $$     $$      $$  $$        $$     $$  $$     $$  $$
             $$     $$      $$  $$$$$$$   $$$$$$$    $$$$$$$     $$$$$$
             $$     $$      $$  $$    $$  $$     $$  $$     $$         $$
             $$     $$      $$  $$    $$  $$     $$  $$     $$         $$
             $$     $$      $$  $$    $$  $$     $$  $$     $$         $$
             $$     $$      $$  $$    $$  $$     $$  $$     $$  $$     $$
             $$      $$$$$$      $$$$$$   $$$$$$$    $$$$$$$     $$$$$$
0RECORD NO. 13         SHTCKT
                       '......... 1234567890123456789012345678901234567899
0* ERROR DATA INPUT * ILLEGAL DATA IN FIELD *'*
 ERROR NUMBER   78    DETECTED BY INCOM=  AT ADDRESS 000202
 CALLED FROM KRAKER= AT ADDRESS 000345
 CALLED FROM INPC=   AT ADDRESS 000075
 CALLED FROM LINEZ   AT  LINE 58
 CALLED FROM INPUT   AT  LINE 24
 CALLED FROM EXEC    AT  LINE 93

1  CSB    NOS/BE L414E        CYBR CMR3 R.0 22.33
 22.42.13.TU633SM  FROM    /B3
 22.42.13.IP  00000320 WORDS - FILE INPUT  , DC 00
 22.42.13.TU6,T30,I020,CM165000,STCSB.T750159,UNDE
 22.42.13.RWODD,4014
 22.42.17.ATTACH,LDFLOW,LDF_OW5,CY=5,ID=T760162.
 22.42.17.LDF_OW.
 22.44.40.FTN - FATAL ERROR   78
 22.44.40.        .155 CP SECONDS EXECUTION TIME
 22.44.40.OP  00000128 WORDS - FILE OUTPUT , DC 40
 22.44.40.MS   82432  WORDS (   82432 MAX USED)
 22.44.40.SCM 164000  WORDS MAXIMUM
 22.44.40.CPA       4.317 SEC.          1.553 ADJ.
 22.44.40.IO        6.909 SEC.          3.743 ADJ.
 22.44.40.CM      534.982 KWS.          7.627 ADJ.
 22.44.40.CRUS                         12.924
 22.44.40.COST                 $          .77
 22.44.40.PP       12.486 SEC.     DATE 11/22/76
 22.44.40.EJ  END OF JOB, B3  T750159.
0
 ***********        TU6BBSM   //// END  OF LIST ////
0
```

Fig. A-17. FORTRAN Error Example.

coding that may have occurred.

Sometimes the use of the tape dump routine may help find a mode error. By use of additional FORTRAN control cards, the content of the output tapes, Tape 1 and Tape 2, will be printed even if the mode error occurs. These cards are placed just before the first EOR card and should be after the DISPOSE, TAPE2 card. The cards are as follows:

1. EXIT.
2. DISPOSE,TAPE1,PR=IBB.
3. DISPOSE,TAPE2,PR=IBB.

The trouble is usually beyond the last information printed as the program execution is ahead of the printer.

A fourth method to find a mode error is the mode override method. By placing a FORTRAN control card, MODE;. immediately following the ATTACH,PDSAP,ID=Txxxxxx,CY=XX card, the program will continue even when a mode error is encountered. The results from the program should not be trusted under this condition. The reasons for the mode error appears on a separate annotation in the dayfile listing.

In an effort to help the user locate some of the more frequent errors, Table A-XIX is a list of some of the error messages and their cause. Other error messages may appear but there should be enough information given to locate the problem. It would be most helpful to have a listing of the program to trace some of the errors when the messages do not specify the exact card causing the problem.

In summary, if there is no success in resolving the

Table A-XIX

Error Messages and Causes

Error Message	Cause
Control card not in proper format or location.	Mis-spelling of keyword. Control cards omitted or out of order.
Illegal Data in the Field (FORTRAN ERROR).	(1) SB=0,EB=0 card not last card in line element list. (2) Number of bus data cards not equal to highest bus number in line element list. (3) Number of bus data cards not equal value on preceding control card.
Use of CON code ( ) not allowed.	Improper CON code, check table of values again.
Too many slack buses.	Two or more Type 3 buses in bus data cards for Load Flow routine. Only one allowed.
Bus ( ) should be connected to line bus of same number.	Bus numbers on bus data cards for Load Flow must match line bus numbers.
Error with ID or C value, line card ( ).	Improper ID or C value on line element data card. Check proper columns and values.
Error with input line card ( ).	Error with wire size or number of ground wires. Check if standard size and in proper columns.
Positive and zero sequence impedance values are zero.	No impedance specified on line element data card for LINEZ routine.
IDB can't be greater than 1 in Load Change routine.	Bus data card in Load Change routine is in error. Check format. No Type 2 or 3 buses allowed.

Table A-XIX (Cont'd)

Error Message	Cause
Error in transformer connection code.	Wrong connection code for transformer or format error. Check with table of codes.
Fault source impedance routine has detected a zero input for 3-ph fault	No 3-ph fault current specified for current source (FA3-0). FA3 can not be zero.
Bus 0 cannot be in sub-system list.	Bus number specified on NOBSYS not equal to number of buses on card following.

problem by using the foregoing information, the advice of a qualified programmer would be helpful. Although extensive use of the program has been made by simulating various actual and theoretical systems, unique situations may be encountered that cannot be simulated with the program without some modification.

AD-A035 292 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCH--ETC F/G 10/2
A USER-ORIENTED POWER DISTRIBUTION SYSTEM ANALYSIS PROGRAM.(U)
DEC 76 J A UNDERWOOD
UNCLASSIFIED GE/EE/76-43 NL

2 OF 3
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A035292

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PAGE

7. Example Problems

Example problems contained in this chapter were selected to illustrate the capability and validity of the PDSAP program. To validate the program results, comparison was made with published results for the same problems.

Problems were chosen for a specific purpose as noted by the introductory paragraph for each problem. Each example has a one-line diagram from which the computer input data was prepared. An illustration for each problem shows the arrangement and format of the data cards for input to the program. In order to conserve space, the FORTRAN cards are not shown. The order and format of the FORTRAN cards is found in Chapter 2.

The computer printout for each problem follows the illustration of the data cards. By choice of the various OUT codes, information not required can be omitted from the printouts.

The user is encouraged to take the one-line diagrams for each problem and duplicate the results to gain familiarity with the program. The introduction to each problem indicates which routines were used and other necessary information.

Example Problem 1.

This example illustrates the use of the LINEZ input routine and the Load Flow routine. It was adapted for the PDSAP program to validate the accuracy of the Load Flow routine (Ref 5:284). The system base is 100 MVA. The negative values indicate power out of the system and the positive values indicate power into the system. All values are in per-unit. Fig. A-18 is the one-line diagram of the system. Fig. A-19 is the data card format and order.

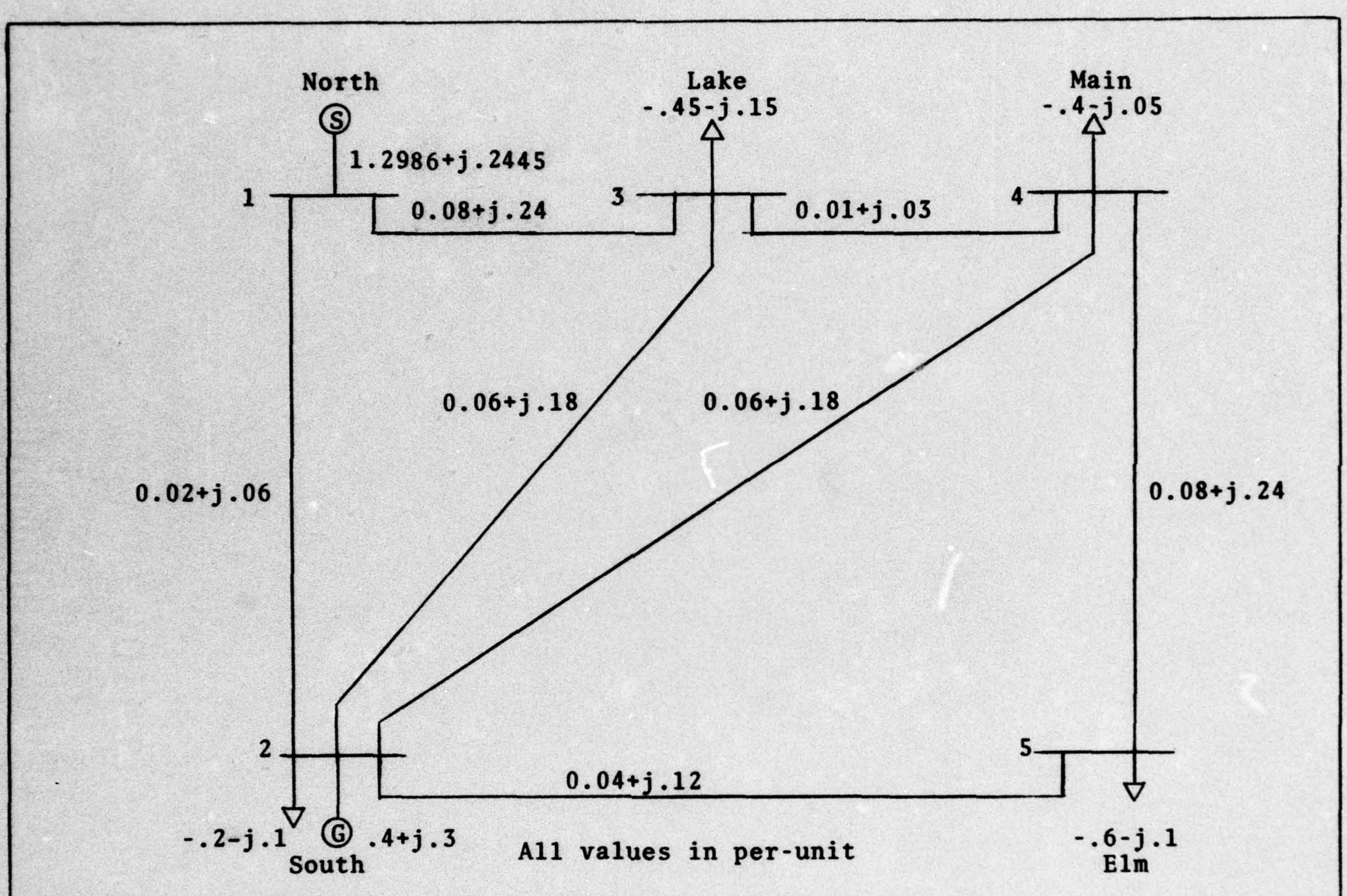


Fig. A-18. Example 1 System Diagram (Ref 5:284)

```
 1  4  MAIN     1.0    0.    -40000    -5000
 1  3  LAKE     1.0    0.    -45000   -15000
BUSCHG  2
 1  4  RED      1.0    0.    -30000   -10000
 1  3  BLUE     1.0    0.    -45000   -15000
BUSCHG  2
 1  5  ELM      1.0    0.    -60000   -10000
 1  4  MAIN     1.0    0.    -40000    -5000
 1  3  LAKE     1.0    0.    -45000   -15000
 1  2  SOUTH    1.0    0.     20000    20000
 3  1  NORTH    1.06   0.
LDFLOW  25  25  .0001  .0001  2
  0  0
  4  5  1.0 13   1.0   .08  .24                   1
  3  4  1.0 13   1.0   .01  .03                   1
  2  5  1.0 13   1.0   .04  .12                   1
  2  4  1.0 13   1.0   .06  .18                   1
  2  3  1.0 13   1.0   .06  .18                   1
  1  3  1.0 13   1.0   .08  .24                   1
  1  2  1.0 13   1.0   .02  .06
SYSPAR
PGMCON  2  1  0
 EXAMPLE PROBLEM #1                 LOAD FLOW ANALYSIS(STAGG)
```

FORTRAN Control Cards

Fig. A-19. Data Card Format, Example 1

```
*****************************************************************
*                                                               *
*     POWER DISTRIBUTION SYSTEM ANALYSIS PROGRAM (PDSAP)        *
*                     TAPE 1 PRINTOUT                           *
*                                                               *
*****************************************************************


*****************************************************************
*                                                               *
*          EXAMPLE PROBLEM #1                                   *
*          LOAD FLOW ANALYSIS(STAGG)                            *
*                                                               *
*****************************************************************

              **** PROGRAM CONTROL CONSTANTS ****

                          CON=  2
                          INP=  1
                          OUT=  0
                          CHG= -0


              *** PROGRAM PARAMETER CONSTANTS ***

   BASE KVA       FREQUENCY      TEMPERATURE       EARTH RESISTIVITY
 100000. KVA       50. HZ        25. DEG. C           100. METER-OHM


*****************************************************************
*                                                               *
*                      LINEZ SUBROUTINE                         *
*           ASSEMBLED INPUT LINE DATA   (PER-UNIT)              *
*                                                               *
*****************************************************************

   CONDUCTOR NO.    1
   FROM - TO      RE(Z)        IM(Z)        RE(ZO)       IM(ZO)
     1    2        .0200        .0600        .0700        .2100

   CONDUCTOR NO.    2
   FROM - TO      RE(Z)        IM(Z)        RE(ZO)       IM(ZO)
     1    3        .0800        .2400        .2800        .8400

   CONDUCTOR NO.    3
   FROM - TO      RE(Z)        IM(Z)        RE(ZO)       IM(ZO)
     2    3        .0600        .1800        .2100        .6300

   CONDUCTOR NO.    4
   FROM - TO      RE(Z)        IM(Z)        RE(ZO)       IM(ZO)
     2    4        .0600        .1800        .2100        .6300
```

```
CONDUCTOR NO.   5
FROM - TO      RE(Z)         IM(Z)         RE(Z0)        IM(Z0)
  2    5         .0400         .1200         .1400         .4200

CONDUCTOR NO.   6
FROM - TO      RE(Z)         IM(Z)         RE(Z0)        IM(Z0)
  3    4         .0100         .0300         .0350         .1050

CONDUCTOR NO.   7
FROM - TO      RE(Z)         IM(Z)         RE(Z0)        IM(Z0)
  4    5         .0800         .2400         .2800         .8400
```

```
******************************************************************************
*                                                                            *
*                  SUMMARIZED INPUT BUS DATA:  PERUNIT                       *
*                  LISTED BY ASCENDING BUS NUMBERS                           *
*                                                                            *
******************************************************************************
```

NO.	TYPE	V(MAG)	V(ANG-DEG)	POWER REAL	POWER REACTIVE	Q(MIN)	Q(MAX)
1	3	1.060	0.0000	0.00000	0.00000	0.0000	0.0000
2	1	1.000	0.0000	.20000	.20000	0.0000	0.0000
3	1	1.000	0.0000	-.45000	-.15000	0.0000	0.0000
4	1	1.000	0.0000	-.40000	-.05000	0.0000	0.0000
5	1	1.000	0.0000	-.60000	-.10000	0.0000	0.0000

```
******************************************************************************
*                                                                            *
*            REORDERED BUSLIST RETURNED BY SUBROUTINE ORDER                  *
*                                                                            *
******************************************************************************

     1    3    2    4    5
```

```
*********************************************************************
*                                                                   *
*                     SORTED LINE INPUT DATA                        *
*                 LISTED BY ASCENDING BUS NUMBERS                   *
*                                                                   *
*********************************************************************
```

SB	EB	G	B	RE(ZO)	IM(ZO)
1	2	.50000E+01	-.15000E+02	.70000E-01	.21000E+00
1	3	.12500E+01	-.37500E+01	.28000E+00	.84000E+00
2	1	.50000E+01	-.15000E+02	.70000E-01	.21000E+00
2	3	.16667E+01	-.50000E+01	.21000E+00	.63000E+00
2	4	.16667E+01	-.50000E+01	.21000E+00	.63000E+00
2	5	.25000E+01	-.75000E+01	.14000E+00	.42000E+00
3	1	.12500E+01	-.37500E+01	.28000E+00	.84000E+00
3	2	.16667E+01	-.50000E+01	.21000E+00	.63000E+00
3	4	.10000E+02	-.30000E+02	.35000E-01	.10500E+00
4	2	.16667E+01	-.50000E+01	.21000E+00	.63000E+00
4	3	.10000E+02	-.30000E+02	.35000E-01	.10500E+00
4	5	.12500E+01	-.37500E+01	.28000E+00	.84000E+00
5	2	.25000E+01	-.75000E+01	.14000E+00	.42000E+00
5	4	.12500E+01	-.37500E+01	.28000E+00	.84000E+00

```
******************************************************************************
*                                                                            *
*         POWER DISTRIBUTION SYSTEM ANALYSIS PROGRAM (PDSAP)                 *
*                         TAPE 2 PRINTOUT                                    *
*                                                                            *
******************************************************************************


******************************************************************************
*                                                                            *
*             EXAMPLE PROBLEM #1                                             *
*            LOAD FLOW ANALYSIS(STAGG)                                       *
*                                                                            *
******************************************************************************

                    **** PROGRAM CONTROL CONSTANTS ****

                                 CON=  2
                                 INP=  1
                                 OUT=  0
                                 CHG= -0

                   *** PROGRAM PARAMETER CONSTANTS ***

   BASE KVA        FREQUENCY       TEMPERATURE         EARTH RESISTIVITY
 100000. KVA        60. HZ          25. DEG. C           100. METER-OHM


******************************************************************************
*                                                                            *
*              RESULTS OF FAST DECOUPLED LOAD FLOW ANALYSIS                  *
*                    ALL MAGNITUDE VALUES ARE PER-UNIT                       *
*                 SYSTEM HAS   5 BUSES:  0 ARE TYPE 2.                       *
*      NUMBER OF TIMES LOAD BUSES WILL BE CHANGED(NLC)=  2.                  *
*                      CONVERGENCE TOLERANCES:                               *
*                           PTOL= .00010                                     *
*                           QTOL= .00010                                     *
*                                                                            *
******************************************************************************
```

```
****************************************************************************
*                                                                          *
*                              SYSTEM SUMMARY                              *
*                                                                          *
*                       CONVERGENCE OBTAINED IN:                           *
*                         8 DELTA THETA AND                                *
*                         8 DELTA V ITERATIONS.                            *
*                                                                          *
****************************************************************************
```

****** SLACK BUS POWER ******

BUS NO.	REAL	REACTIVE	MAG.
1	1.29822	.24445	1.32103

```
****************************************************************************
*                                                                          *
*                         CALCULATED LINE FLOWS                            *
* (THE LINE FLOWS ARE DEFINED POSITIVE WHEN FLOWING OUT FROM THE BUS)      *
*                                                                          *
****************************************************************************
```

LINE		POWER		LINE		POWER	
FROM	TO	REAL	REACTIVE	FROM	TO	REAL	REACTIVE
1	2	.88955	.13865	2	1	-.87512	-.09537
1	3	.40867	.10580	3	1	-.39598	-.05774
2	3	.24688	.00146	3	2	-.24311	-.07014
2	4	.27932	.08061	4	2	-.27460	-.05545
2	5	.54891	.13330	5	2	-.53703	-.09766
3	4	.18909	-.01213	4	3	-.18874	.01319
4	5	.06334	.00326	5	4	-.06302	-.00231

```
****************************************************************************
*                                                                          *
*                            OUTPUT BUS DATA                               *
*                                                                          *
****************************************************************************
```

					POWER	
NO.	TYPE	NAME	V(MAG)	V(ANG-DEG)	REAL	REACTIVE
1	3	NORTH	1.0600	0.0000	1.29822	.24445
2	1	SOUTH	1.0365	-2.6397	.20000	.20000
3	1	LAKE	1.0088	-4.8077	-.45000	-.15000
4	1	MAIN	1.0073	-5.1344	-.40000	-.05000
5	1	ELM	1.0016	-5.9830	-.50000	-.10000

****

```
*****************************************************************
*                    LOAD FLOW BUS CHANGE                       *
*                     CHANGE NUMBER  1                          *
*                NUMBER OF BUSES CHANGED  2                     *
*                                                               *
*****************************************************************

*****************************************************************
*                                                               *
*                       BUS CHANGE DATA                         *
*                                                               *
*****************************************************************
```

NO.	TYPE	NAME	V(MAG)	V(ANG-DEG)	POWER REAL	POWER REACTIVE
3	1	BLUE	1.000	0.000	-.45000	-.15000
4	1	RED	1.000	0.000	-.30000	-.10000

```
*****************************************************************
*                                                               *
*                       SYSTEM SUMMARY                          *
*                                                               *
*                 CONVERGENCE OBTAINED IN:                      *
*                  14 DELTA THETA AND                           *
*                  14 DELTA V ITERATIONS.                       *
*                                                               *
*****************************************************************
```

****** SLACK BUS POWER ******

BUS NO.	REAL	REACTIVE	MAG.
1	1.19249	.27750	1.22437

```
*****************************************************************
*                                                               *
*                   CALCULATED LINE FLOWS                       *
* (THE LINE FLOWS ARE DEFINED POSITIVE WHEN FLOWING OUT FROM THE BUS)*
*                                                               *
*****************************************************************
```

LINE FROM	LINE TO	POWER REAL	POWER REACTIVE	LINE FROM	LINE TO	POWER REAL	POWER REACTIVE
1	2	.81844	.16079	2	1	-.80605	-.12364
1	3	.37404	.11682	3	1	-.36311	-.08402
2	3	.22485	.00057	3	2	-.22157	-.03072
2	4	.24783	.00387	4	2	-.24391	-.03210
2	5	.53340	.13920	5	2	-.52208	-.10525
3	4	.13468	.01474	4	3	-.13450	-.01419
4	5	.07840	-.00371	5	4	-.07792	.00517

OUTPUT BUS DATA

NO.	TYPE	NAME	V(MAG)	V(ANG-DEG)	POWER REAL	POWER REACTIVE
1	3	NORTH	1.0500	0.0000	1.19249	.27760
2	1	SOUTH	1.0364	-2.3942	.20000	.20000
3	1	BLUE	1.0082	-4.3150	-.45000	-.15000
4	1	RED	1.0064	-4.5358	-.30000	-.10000
5	1	ELM	1.0012	-5.6227	-.50000	-.10000

LOAD FLOW BUS CHANGE
CHANGE NUMBER 2
NUMBER OF BUSES CHANGED 2

BUS CHANGE DATA

NO.	TYPE	NAME	V(MAG)	V(ANG-DEG)	POWER REAL	POWER REACTIVE
4	1	MAIN	1.000	0.000	-.40000	-.05000
3	1	LAKE	1.000	0.000	-.45000	-.15000

SYSTEM SUMMARY

CONVERGENCE OBTAINED IN:
19 DELTA THETA AND
18 DELTA V ITERATIONS.

****** SLACK BUS POWER ******

BUS NO.	REAL	REACTIVE	MAG.
1	1.29815	.24453	1.32098

CALCULATED LINE FLOWS

(THE LINE FLOWS ARE DEFINED POSITIVE WHEN FLOWING OUT FROM THE BUS)

LINE FROM	LINE TO	POWER REAL	POWER REACTIVE	LINE FROM	LINE TO	POWER REAL	POWER REACTIVE
1	2	.88949	.13871	2	1	-.87505	-.09544
1	3	.40866	.10582	3	1	-.39597	-.06775
2	3	.24688	.08146	3	2	-.24311	-.07014
2	4	.27932	.08062	4	2	-.27460	-.06645
2	5	.54830	.13336	5	2	-.53702	-.09771
3	4	.18909	-.01211	4	3	-.18874	.01317
4	5	.06333	.00329	5	4	-.06302	-.00234

OUTPUT BUS DATA

NO.	TYPE	NAME	V(MAG)	V(ANG-DEG)	POWER REAL	POWER REACTIVE
1	3	NORTH	1.0600	0.0000	1.29815	.24453
2	1	SOUTH	1.0365	-2.6395	.20000	.20000
3	1	LAKE	1.0087	-4.8075	-.45000	-.15000
4	1	MAIN	1.0072	-5.1342	-.40000	-.05000
5	1	ELM	1.0015	-5.9825	-.50000	-.10000

Example Problem 2

This example illustrates the use of the LINDATA input routine and the Short Circuit routine. It is adapted from a text to show the validity of the PDSAP program in calculation of fault currents (Ref 3:11). Fig. A-20 is the one-line diagram and Fig. A-21 illustrates the format and order of the data cards.

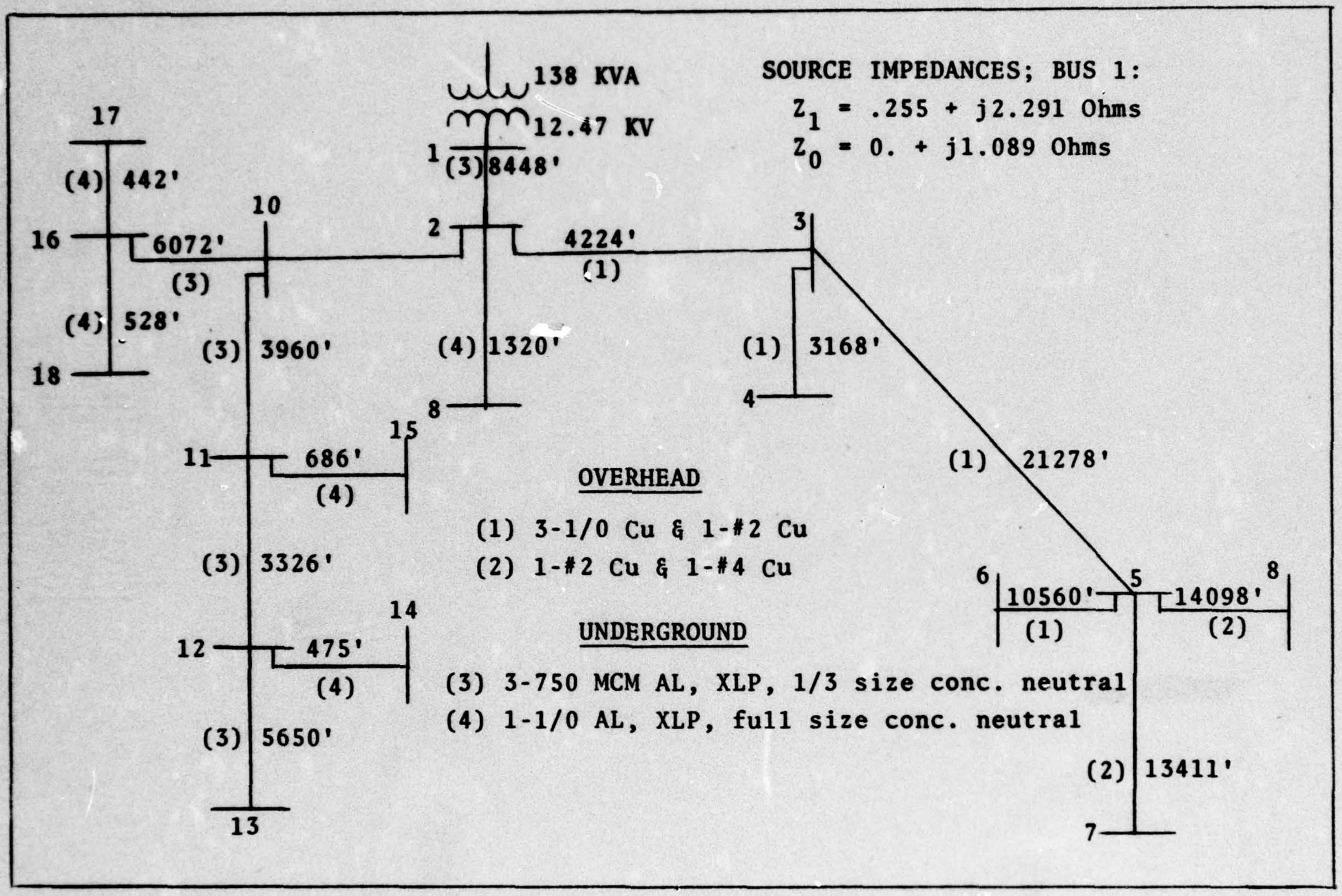


Fig. A-20. System Diagram, Example Problem 2 (Ref 3:40)

```
  1  3  5  6
NOBSYS  4
NOFALT
  7
NOFALT  1   20.         1   7.2
  3  4  5  6  8
NOFALT  5   20.         3 12.47
NOMUTL
  1  7.1995579      0.0     345.44 -3104.09     339.84 -3778.06
CURSOR  1
SHTCKT  1
  0  0
 16 18 7.20 3    523  1 105500
 16 17 7.20 3    422  1 105500
 10 1612.47 3   6072  3 750000
 11 15 7.20 1    686  1 105500
  6 1312.47 3   5650  3 750000
 12 1312.47 3   5650  3 750000
 12 14 7.20 3    475  1 105500
 11 1212.47 3   3325  3 750000
 10 1112.47 3   3960  3 750000
  2 1012.47 3   4699  3 750000
  2  9 7.20 3   1320  1 105500
  5  8 7.20 1  14098  1  66370          41740                         1
  5  7 7.20 1  13411  1  66370          41740                         1
  5   612.47 1  10560  3 105500          66370                         1
  3   512.47 1  21278  3 105500          66370                         1
  3   412.47 1   3168  3 105500          66370                         1
  2   312.47 1   4224  3 105500          66370                         1
  1   212.47 3   8448  3 750000
SYSPAR
PGMCON  3  0  4
EXAMPLE PROBLEM  #2                 SHORT CIRCUIT ANALYSIS
```

FORTRAN Control Cards

Fig. A-21. Data Card Format, Example 2

```
****************************************************************
*                                                              *
*   POWER DISTRIBUTION SYSTEM ANALYSIS PROGRAM (PDSAP)         *
*                   TAPE 1 PRINTOUT                            *
*                                                              *
****************************************************************


****************************************************************
*                                                              *
*            EXAMPLE PROBLEM  #2                               *
*            SHORT CIRCUIT ANALYSIS                            *
*                                                              *
****************************************************************

              **** PROGRAM CONTROL CONSTANTS ****

                         CON=  3
                         INP=  0
                         OUT=  4
                         CHG= -0

             *** PROGRAM PARAMETER CONSTANTS ***

   BASE KVA        FREQUENCY      TEMPERATURE      EARTH RESISTIVITY
 100000. KVA        60. HZ         25. DEG. C         100. METER-OHM


****************************************************************
*                                                              *
*                  LINDATA SUBROUTINE                          *
*          ASSEMBLED INPUT LINE DATA  (PER-UNIT)               *
*                                                              *
****************************************************************

   CONDUCTOR NO.   1
   FROM - TO     RE(Z)        IM(Z)        RE(Z0)       IM(Z0)
     1    2        .2977        .3167        .6454        .1695

   CONDUCTOR NO.   2
   FROM - TO     RE(Z)        IM(Z)        RE(Z0)       IM(Z0)
     2    3        .2856        .3773        .6070       1.0602

   CONDUCTOR NO.   3
   FROM - TO     RE(Z)        IM(Z)        RE(Z0)       IM(Z0)
     3    4        .2142        .2830        .4553        .7951

   CONDUCTOR NO.   4
   FROM - TO     RE(Z)        IM(Z)        RE(Z0)       IM(Z0)
     3    5       1.4387       1.9008       3.0579       5.3404

   CONDUCTOR NO.   5
   FROM - TO     RE(Z)        IM(Z)        RE(Z0)       IM(Z0)
     5    6        .7140        .9433       1.5175       2.6504
```

```
CONDUCTOR NO.   6
FROM - TO     RE(Z)        IM(Z)        RE(ZO)       IM(ZO)
  5    7       1.4404       1.2457       2.6315       3.7903

CONDUCTOR NO.   7
FROM - TO     RE(Z)        IM(Z)        RE(ZO)       IM(ZO)
  5    8       1.5142       1.3095       2.7663       3.9844

CONDUCTOR NO.   8
FROM - TO     RE(Z)        IM(Z)        RE(ZO)       IM(ZO)
  2    9        .1740        .0461        .4837        .2210

CONDUCTOR NO.   9
FROM - TO     RE(Z)        IM(Z)        RE(ZO)       IM(ZO)
  2   10        .1656        .1762        .3590        .0943

CONDUCTOR NO.  10
FROM - TO     RE(Z)        IM(Z)        RE(ZO)       IM(ZO)
 10   11        .1396        .1485        .3025        .0795

CONDUCTOR NO.  11
FROM - TO     RE(Z)        IM(Z)        RE(ZO)       IM(ZO)
 11   12        .1172        .1247        .2541        .0667

CONDUCTOR NO.  12
FROM - TO     RE(Z)        IM(Z)        RE(ZO)       IM(ZO)
 12   14        .0526        .0166        .1752        .0795

CONDUCTOR NO.  13
FROM - TO     RE(Z)        IM(Z)        RE(ZO)       IM(ZO)
 12   13        .1991        .2118        .4317        .1134

CONDUCTOR NO.  14
FROM - TO     RE(Z)        IM(Z)        RE(ZO)       IM(ZO)
 11   15        .0464        .0613        .0703        .2555

CONDUCTOR NO.  15
FROM - TO     RE(Z)        IM(Z)        RE(ZO)       IM(ZO)
 10   15        .2140        .2276        .4633        .1218

CONDUCTOR NO.  16
FROM - TO     RE(Z)        IM(Z)        RE(ZO)       IM(ZO)
 16   17        .0556        .0147        .1556        .0707

CONDUCTOR NO.  17
FROM - TO     RE(Z)        IM(Z)        RE(ZO)       IM(ZO)
 16   18        .0696        .0184        .1959        .0884
```

```
*****************************************************************
*                                                               *
*                  SHORT CIRCUIT INPUT DATA                     *
*                                                               *
*****************************************************************

SOURCE IMPEDANCE BUS NO.  1      VOLTS L-N(KV)      7.20      0.00
3-PH FAULT CURRENT(AMPS)    345.44 -3104.09
PH-GND FAULT CURRENT(AMPS )    339.84 -3778.06
FAULT Z(OHMS) -0.0 -0.0;  NEUT Z(OHMS) -0.0 -0.0


FAULT  IMPEDANCE(ZF)(OHMS)=20.000 -0.000
PHASE= 3 BUS VOLTAGE(KV)= 12.47
BUS  3
BUS  4
BUS  5
BUS  6
BUS  8

FAULT  IMPEDANCE(ZF)(OHMS)=20.000 -0.000
PHASE= 1 BUS VOLTAGE(KV)=  7.20
BUS  7
```

```
POWER DISTRIBUTION SYSTEM ANALYSIS PROGRAM (PDSAP)
TAPE 2 PRINTOUT


EXAMPLE PROBLEM  #2
SHORT CIRCUIT ANALYSIS


**** PROGRAM CONTROL CONSTANTS ****

CON=  3
INP=  0
OUT=  4
CHG= -0


*** PROGRAM PARAMETER CONSTANTS ***

 BASE KVA       FREQUENCY      TEMPERATURE        EARTH RESISTIVITY
100000. KVA       60. HZ         25. DEG. C          100. METER-OHM


RESULTS OF SHORT CIRCUIT ANALYSIS
ALL VALUES ARE PER-UNIT
SYSTEM HAS  18 BUSES. FAULT CODE(SCOP) IS -0 .
THERE ARE   1 SUBSYSTEM STUDIES(ISYS).


SUBSYSTEM STUDY NO.   1.
NUMBER OF BUSSES IN THIS SYSTEM IS:  4.
```

```
                     ********************************
                     * FAULT SUMMARY FOR BUS    3 *
                     *    ZF= (12.86, 0.00) P.U.   *
                     *    ZG= ( 0.00, 0.00) P.U.   *
                     ********************************

  THREE-PHASE        PHASE-GROUND        PHASE-PHASE        PH-PH-GROUND
****************   ****************   ****************   ****************
IF(MAG)=   .0726   IF(MAG)=   .0718   IF(MAG)=   .1155   IF(MAG)=   .0372
X/R=    .159       X/R=    .152       X/R=    .302       X/R=    .075
****************   ****************   EF(A)= 1.0000      EF(A)= 1.0060
                                      EF(B)= 1.0081      EF(B)=  .4784
                                      EF(C)=  .7551      EF(C)=  .4784
                                      ****************   IF(B)=  .3949
                                                         X/R(B)=   3.035
                                                         IF(C)=   .3607
                                                         X/R(C)=   2.719
                                                         ****************

  BUS VOLTAGES        PHASE VOLTAGES
BUS     V(MAG)          A    B    C
  1        .9770       .98  .98 1.01
  6        .9333       .92 1.00 1.01
  3        .9333       .92 1.00 1.01
  5        .9333       .92 1.00 1.01

  LINE CURRENTS       LINE CURRENTS
LINE      FAULT(I)    FAULT(I) PH-A
  6   5   0.0000            0.0000
  5   3   0.0000            0.0000
1
                     ********************************
                     * FAULT SUMMARY FOR BUS    5 *
                     *    ZF= (12.86, 0.00) P.U.   *
                     *    ZG= ( 0.00, 0.00) P.U.   *
                     ********************************

  THREE-PHASE        PHASE-GROUND        PHASE-PHASE        PH-PH-GROUND
****************   ****************   ****************   ****************
IF(MAG)=   .0642   IF(MAG)=   .0603   IF(MAG)=   .0909   IF(MAG)=   .0334
X/R=    .270       X/R=    .326       X/R=    .472       X/R=    .212
****************   ****************   EF(A)= 1.0000      EF(A)= 1.0309
                                      EF(B)=  .9171      EF(B)=  .4291
                                      EF(C)=  .5849      EF(C)=  .4291
                                      ****************   IF(B)=  .2005
                                                         X/R(B)=   2.128
                                                         IF(C)=   .1751
                                                         X/R(C)=   1.614
                                                         ****************

  BUS VOLTAGES        PHASE VOLTAGES
BUS     V(MAG)          A    B    C
  1        .9592       .97  .98 1.01
  6        .8251       .78 1.07  .99
  3        .9255       .91 1.00 1.01
  5        .8251       .78 1.07  .99

  LINE CURRENTS       LINE CURRENTS
LINE      FAULT(I)    FAULT(I) PH-A
  6   5   0.0000            0.0000
  5   3    .0642             .0603
0
```

```
1
                         ******************************
                         * FAULT SUMMARY FOR BUS    1 *
                         *    ZF= ( 0.00, 0.00) P.U.  *
                         *    ZG= ( 0.00, 0.00) P.U.  *
                         ******************************

  THREE-PHASE        PHASE-GROUND        PHASE-PHASE         PH-PH-GROUND
****************   ****************   ****************   ****************
IF(MAG)=   .6746   IF(MAG)=   .8193   IF(MAG)=   .5942   IF(MAG)=  1.0422
X/R=   8.986       X/R=  11.117       X/R=    8.986      X/R=   17.501
****************   ****************   EF(A)= 1.0000      EF(A)=   .7298
                                      EF(B)=  .5000      EF(B)= 0.0000
                                      EF(C)=  .5000      EF(C)= 0.0000
                                      ****************   IF(B)=   .7516
                                                         X/R(B)=   1.340
                                                         IF(C)=   .8034
                                                         X/R(C)=    .942
                                                         ****************

  BUS VOLTAGES       PHASE VOLTAGES
BUS    V(MAG)          A     B    C
  1      0.0000      0.00  .94  .89
  6       .0000      0.00  .94  .89
  3       .0000      0.00  .94  .89
  5       .0000      0.00  .94  .89

  LINE CURRENTS      LINE CURRENTS
LINE      FAULT(I)   FAULT(I) PH-A
  6   5   0.0000          0.0000
  5   3   0.0000          0.0000
1
                         ******************************
                         * FAULT SUMMARY FOR BUS    6 *
                         *    ZF= (12.86, 0.00) P.U.  *
                         *    ZG= ( 0.00, 0.00) P.U.  *
                         ******************************

  THREE-PHASE        PHASE-GROUND        PHASE-PHASE         PH-PH-GROUND
****************   ****************   ****************   ****************
IF(MAG)=   .0605   IF(MAG)=   .0555   IF(MAG)=   .0818   IF(MAG)=   .0316
X/R=    .318       X/R=     .397      X/R=     .537      X/R=     .271
****************   ****************   EF(A)= 1.0000      EF(A)= 1.0441
                                      EF(B)=  .8805      EF(B)=  .4060
                                      EF(C)=  .5270      EF(C)=  .4060
                                      ****************   IF(B)=   .1611
                                                         X/R(B)=   2.044
                                                         IF(C)=   .1389
                                                         X/R(C)=   1.445
                                                         ****************

  BUS VOLTAGES       PHASE VOLTAGES
BUS    V(MAG)          A     B    C
  1       .9670      .97  .99 1.01
  6       .7776      .71 1.10  .99
  3       .9239      .91 1.00 1.01
  5       .8228      .77 1.06 1.00

  LINE CURRENTS      LINE CURRENTS
LINE      FAULT(I)   FAULT(I) PH-A
  6   5    .0605           .0555
  5   3    .0605           .0555
1
```

Example Problem 3

This example illustrates the use of the LINDATA input routine and both the Load Flow and Short Circuit routines. Fig. A-22 is the one-line diagram of a system specifically designed to test the total PDSAP program (Ref 2:258). This example highlights the capability of the PDSAP program to utilize information other than impedance values to make a system analysis.

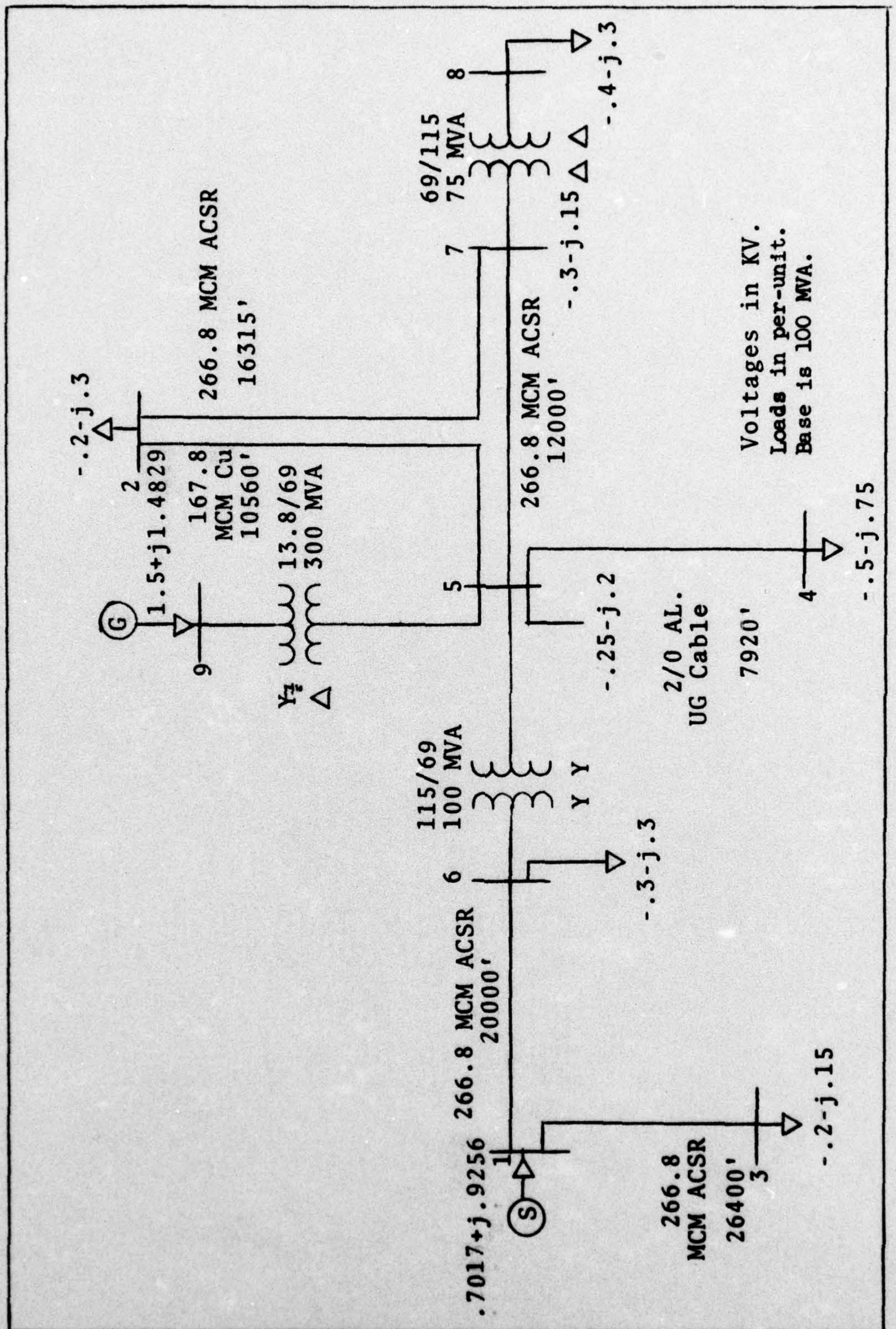


Fig. A-22. System Diagram, Example 3

(Ref 2:258)

```
 1  9
NOBSYS  2
NOFALT
NOMUTL
 1  66.395281       0.0    575.73 -1078.92    434.94   -754.27
CURSOR  1
SHTCKT  1
 2   9   INDIA                    150000           0              150000
 1   8   HOTEL                    -40000      -30000
 1   7   GOLF                     -30000      -15000
 1   6   CHARLIE                  -30000      -30000
 1   5   DELTA                    -25000      -20000
 1   4   ECHO                     -50000      -75000
 1   3   BRAVO                    -20000      -15000
 1   2   FOXTROT                  -20000      -30000
 3   1   ALPHA     1.0  0.0
LDFLOW 999 999    .001    .001
  0  0
  7  8  115 5         23  75000          69          1.0
  5  7   69 2  12000   3 266800
  2  7   69 2  16315   3 266300
  2  5   69 1  10560   3 167800
  4  5   69 3   7920   3 133100
  5  6  115 6         13 100000          69          1.0
  5  9   69 7         43 300000        13.8          1.0
  1  6  115 2  20000   3 266800
  1  3  115 2  26400   3 266300
SYSPAR
PSMCON   5   0 12
 EXAMPLE PROBLEM #3                  LOAD FLOW AND SHORT CKT ANALYSIS
```

FORTRAN Control Cards

Fig. A-23. Data Card Format, Example 3

```
*****************************************************************
*                                                               *
*   POWER DISTRIBUTION SYSTEM ANALYSIS PROGRAM (PDSAP)          *
*                     TAPE 1 PRINTOUT                           *
*                                                               *
*****************************************************************


*****************************************************************
*                                                               *
*             EXAMPLE PROBLEM #3                                *
*             LOAD FLOW AND SHORT CKT ANALYSIS                  *
*                                                               *
*****************************************************************

              **** PROGRAM CONTROL CONSTANTS ****

                          CON=  5
                          INP=  0
                          OUT= 12
                          CHG= -0

              *** PROGRAM PARAMETER CONSTANTS ***

   BASE KVA        FREQUENCY       TEMPERATURE        EARTH RESISTIVITY
 100000. KVA         60. HZ          25. DEG. C          100. METER-OHM


*****************************************************************
*                                                               *
*                    LINDATA SUBROUTINE                         *
*          ASSEMBLED INPUT LINE DATA  (PER-UNIT)                *
*                                                               *
*****************************************************************

   CONDUCTOR NO.    1
   FROM - TO      RE(Z)          IM(Z)         RE(Z0)         IM(Z0)
     1    3        .0132          .0293          .0240          .1036

   CONDUCTOR NO.    2
   FROM - TO      RE(Z)          IM(Z)         RE(Z0)         IM(Z0)
     1    6        .0100          .0222          .0192          .0785

   TRANSFORMER, LTC NO.    1
   FROM - TO      RE(Z)          IM(Z)         RE(Z0)         IM(Z0)
     5    3       0.0000          .0293         0.0000          .0293
   TAP        TMN        TMX      CONEC CODE
 1.00000    .90000    1.10000          5

   TRANSFORMER, AUTO. NO.    1
   FROM - TO      RE(Z)          IM(Z)         RE(Z0)         IM(Z0)
     5    5       0.0000          .0464         0.0000         0.0000
 TAP      CONEC CODE
1.000          1
```

```
CONDUCTOR NO.   3
FROM - TO       RE(Z)         IM(Z)         RE(Z0)        IM(Z0)
   4   5          .0295         .0154         .0791         .0412

CONDUCTOR NO.   4
FROM - TO       RE(Z)         IM(Z)         RE(Z0)        IM(Z0)
   2   5          .0147         .0344         .0257         .1170

CONDUCTOR NO.   5
FROM - TO       RE(Z)         IM(Z)         RE(Z0)        IM(Z0)
   2   7          .0227         .0502         .0413         .1779

CONDUCTOR NO.   6
FROM - TO       RE(Z)         IM(Z)         RE(Z0)        IM(Z0)
   5   7          .0157         .0370         .0304         .1308

TRANSFORMER, FIXED NO.    1
FROM - TO       RE(Z)         IM(Z)         RE(Z0)        IM(Z0)
   7   8        0.0000          .1486       0.0000          .1485
 TAP      CONEC CODE
1.00000         2


**************************************************************************
*                                                                        *
*                SUMMARIZED INPUT BUS DATA: PER-UNIT                     *
*                  LISTED BY ASCENDING BUS NUMBERS                       *
*                                                                        *
**************************************************************************


                                        POWER
NO. TYPE V(MAG)   V(ANG-DEG)      REAL      REACTIVE      Q(MIN)     Q(MAX)

 1    3    1.000      0.0000     0.00000    0.00000      0.0000     0.0000
 2    1    1.000      0.0000     -.20000    -.30000      0.0000     0.0000
 3    1    1.000      0.0000     -.20000    -.15000      0.0000     0.0000
 4    1    1.000      0.0000     -.50000    -.75000      0.0000     0.0000
 5    1    1.000      0.0000     -.25000    -.20000      0.0000     0.0000
 6    1    1.000      0.0000     -.30000    -.30000      0.0000     0.0000
 7    1    1.000      0.0000     -.30000    -.15000      0.0000     0.0000
 8    1    1.000      0.0000     -.40000    -.30000      0.0000     0.0000
 9    2    1.000      0.0000     1.50000    0.00000      0.0000     1.5000


**************************************************************************
*                                                                        *
*          REORDERED BUSLIST RETURNED BY SUBROUTINE ORDER                *
*                                                                        *
**************************************************************************


     3    1    4    6    8    9    2    5    7
```

SHORT CIRCUIT INPUT DATA

SOURCE IMPEDANCE BUS NO. 1 VOLTS L-N(KV) 55.40 0.00
3-PH FAULT CURRENT(AMPS) 575.73 -1078.32
PH-GND FAULT CURRENT(AMPS) 434.94 -754.27
FAULT Z(OHMS) -0.0 -0.0; NEUT Z(OHMS) -0.0 -0.0

SORTED LINE INPUT DATA
LISTED BY ASCENDING BUS NUMBERS

SB	EB	G	B	RE(ZO)	IM(ZO)
0	1	.11468E+01	-.21491E+01	.47757E+00	.77415E+00
0	9	0.	0.	0.	.29263E-01
1	0	.11468E+01	-.21491E+01	.47757E+00	.77415E+00
1	3	.12830E+02	-.28359E+02	.24049E-01	.10361E+00
1	6	.16935E+02	-.37434E+02	.18219E-01	.78496E-01
2	5	.10508E+02	-.24599E+02	.26692E-01	.11598E+00
2	7	.74735E+01	-.16520E+02	.41283E-01	.17787E+00
3	1	.12830E+02	-.28359E+02	.24049E-01	.10361E+00
4	5	.26579E+02	-.13827E+02	.78052E-01	.41155E-01
5	2	.10508E+02	-.24599E+02	.26692E-01	.11598E+00
5	4	.26579E+02	-.13827E+02	.78052E-01	.41155E-01
5	6	0.	-.21532E+02	0.	0.
5	7	.10161E+02	-.22461E+02	.30365E-01	.13083E+00
5	9	0.	-.34173E+02	0.	.29263E-01
6	1	.16935E+02	-.37434E+02	.18219E-01	.78496E-01
6	5	0.	-.21532E+02	.10000E+11	0.
7	2	.74735E+01	-.16520E+02	.41283E-01	.17787E+00
7	5	.10161E+02	-.22461E+02	.30365E-01	.13083E+00
7	8	0.	-.67293E+01	.10000E+11	0.
8	7	0.	-.67293E+01	.10000E+11	0.
9	0	0.	0.	0.	.29263E-01
9	5	0.	-.34173E+02	.10000E+11	0.

```
*******************************************************************************
*                                                                             *
*        POWER DISTRIBUTION SYSTEM ANALYSIS PROGRAM (PDSAP)                   *
*                       TAPE 2 PRINTOUT                                       *
*                                                                             *
*******************************************************************************


*******************************************************************************
*                                                                             *
*            EXAMPLE PROBLEM #3                                               *
*            LOAD FLOW AND SHORT CKT ANALYSIS                                 *
*                                                                             *
*******************************************************************************

                  **** PROGRAM CONTROL CONSTANTS ****

                             CON=  5
                             INP=  0
                             OUT= 12
                             CHG= -0


                  *** PROGRAM PARAMETER CONSTANTS ***

   BASE KVA       FREQUENCY      TEMPERATURE       EARTH RESISTIVITY
 100000. KVA       60. HZ         25. DEG. C           100. METER-OHM


*******************************************************************************
*                                                                             *
*          RESULTS OF FAST DECOUPLED LOAD FLOW ANALYSIS                       *
*              ALL MAGNITUDE VALUES ARE PER-UNIT                              *
*            SYSTEM HAS    9 BUSES;  1 ARE TYPE 2.                            *
*     NUMBER OF TIMES LOAD BUSES WILL BE CHANGED(NLC)= -0.                    *
*                  CONVERGENCE TOLERANCES:                                    *
*                       PTOL= .00100                                          *
*                       QTOL= .00100                                          *
*                                                                             *
*******************************************************************************

        **** BUS NO.     9 EXCEEDED ITS MAXIMUM Q LIMIT
             Q SPECIFIED:  1.5000 PER-UNIT.
             Q CALCULATED:  1.5127 PER-UNIT.
             AMOUNT EXCEEDED:  .85 PERCENT.
```

SYSTEM SUMMARY

CONVERGENCE OBTAINED IN:
5 DELTA THETA AND
5 DELTA V ITERATIONS.

****** SLACK BUS POWER ******

BUS NO.	REAL	REACTIVE	MAG.
1	.70173	.92561	1.16154

CALCULATED LINE FLOWS
(THE LINE FLOWS ARE DEFINED POSITIVE WHEN FLOWING OUT FROM THE BUS)

LINE FROM	LINE TO	POWER REAL	POWER REACTIVE	LINE FROM	LINE TO	POWER REAL	POWER REACTIVE
1	3	.20084	.15186	3	1	-.20000	-.15000
1	6	.50089	.77375	6	1	-.49236	-.75491
2	5	-.35554	-.37255	5	2	.35007	.39294
2	7	.15565	.07255	7	2	-.15483	-.07086
4	5	-.49990	-.74964	5	4	.52773	.75417
5	6	-.19236	-.44306	6	5	.19236	.45491
5	7	.55444	.44810	7	5	-.54514	-.42756
5	9	-1.50000	-1.35233	9	5	1.50000	1.48286
7	8	.40000	.34842	8	7	-.40000	-.30000

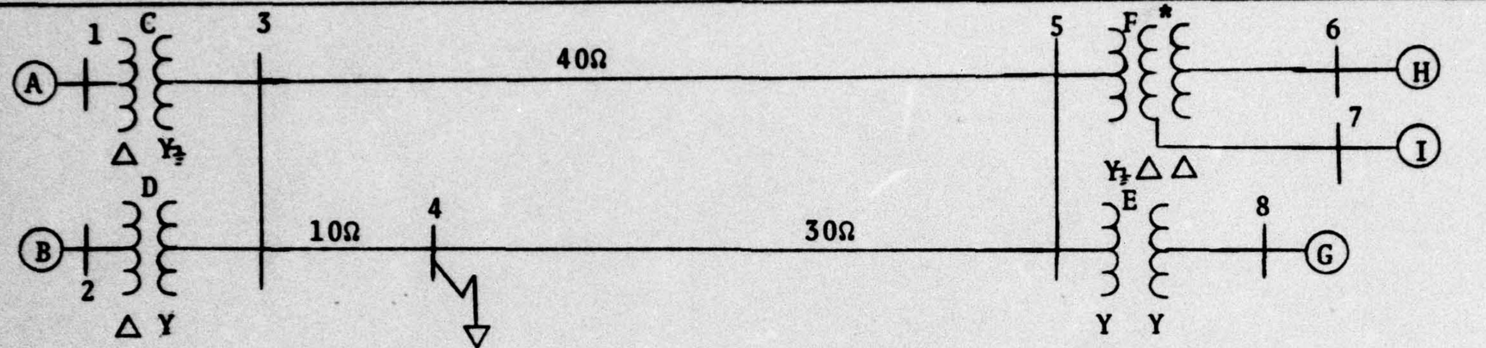
OUTPUT BUS DATA

NO.	TYPE	NAME	V(MAG)	V(ANG-DEG)	POWER REAL	POWER REACTIVE
1	3	ALPHA	1.0000	0.0000	.70173	.92561
2	1	FOXTROT	.9370	-1.1754	-.20000	-.30000
3	1	BRAVO	.9929	-.2232	-.20000	-.15000
4	1	ECHO	.9277	.1930	-.50000	-.75000
5	1	DELTA	.9563	-.7434	-.25000	-.20000
6	1	CHARLIE	.9778	-.1360	-.30000	-.30000
7	1	GOLF	.9233	-1.5815	-.30000	-.15000
8	1	HOTEL	.8750	-5.7588	-.40000	-.30000
9	2	INDIA	.9957	1.8910	1.50000	1.48286

```
*****************************************************************
*                                                               *
*                  OUTPUT TRANSFORMER DATA                      *
*                                                               *
*****************************************************************

          SB   EB      TAP       TAP(MIN)       TAP(MAX)

          5    6     1.00000    -.00000        -.00000
          5    9     1.00000     .90000        1.10000
          7    8     1.00000    -.00000        -.00100

*****************************************************************
*                                                               *
*              RESULTS OF SHORT CIRCUIT ANALYSIS                *
*                  ALL VALUES ARE PER-UNIT                      *
*       SYSTEM HAS   9 BUSES. FAULT CODE(SCOP) IS -0 .          *
*          THERE ARE   1 SUBSYSTEM STUDIES(ISYS).               *
*                                                               *
*****************************************************************

*****************************************************************
*                                                               *
*                  SUBSYSTEM STUDY NO.    1.                    *
*            NUMBER OF BUSSES IN THIS SYSTEM IS:  2.            *
*                                                               *
*****************************************************************

1
                    ******************************
                    * FAULT SUMMARY FOR BUS    1 *
                    *   ZF= ( 0.00, 0.00) P.U.   *
                    *   ZG= ( 0.00, 0.00) P.U.   *
                    ******************************

 THREE-PHASE        PHASE-GROUND       PHASE-PHASE        PH-PH-GROUND
****************   ****************   ****************   ****************
IF(MAG)=  2.4359   IF(MAG)=  1.7343   IF(MAG)=  2.1095   IF(MAG)=  1.3459
X/R=   1.874       X/R=   1.734       X/R=   1.874       X/R=   1.564
****************   ****************   EF(A)= 1.0000      EF(A)= 1.2242
                                      EF(B)=  .5000      EF(B)= 0.0000
                                      EF(C)=  .5000      EF(C)= 0.0000
                                      ****************   IF(B)= 2.2467
                                                         X/R(B)=   5.302
                                                         IF(C)=  2.1812
                                                         X/R(C)=    .965
                                                         ****************
1
                    ******************************
                    * FAULT SUMMARY FOR BUS    9 *
                    *   ZF= ( 0.00, 0.00) P.U.   *
                    *   ZG= ( 0.00, 0.00).P.U.   *
                    ******************************

 THREE-PHASE        PHASE-GROUND       PHASE-PHASE        PH-PH-GROUND
****************   ****************   ****************   ****************
IF(MAG)=  1.9891   IF(MAG)=  2.9047   IF(MAG)=  1.7217   IF(MAG)=  5.3859
X/R=   2.263       X/R=   2.335       X/R=   2.263       X/R=   2.551
****************   ****************   EF(A)= 1.0000      EF(A)=  .1576
                                      EF(B)=  .5000      EF(B)= 0.0000
                                      EF(C)=  .5000      EF(C)= 0.0000
                                      ****************   IF(B)= 3.1339
                                                         X/R(B)=   1.412
                                                         IF(C)=  3.2571
                                                         X/R(C)=    .185
                                                         ****************
```

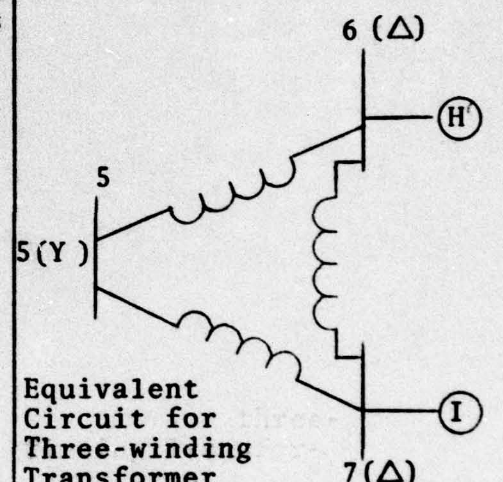
Example Problem 4

This example illustrates the use of the LINEZ input routine and the Short Circuit routine. This example was adapted for use with the PDSAP program to show the capability of the program to calculate line currents (Ref 7:2-34). Fig. A-24 is the one-line diagram of the system. System base for this example is 50 MVA. Note that the example has a three-winding transformer and the program equivalent is shown in Detail A. Fig. A-25 illustrates the format and order of the data cards.



Source A: 50 MVA, 12 KV, Subtransient react. 30%
Source B: 20 MVA, 12 KV, Subtransient react. 35%
Source H: 50 MVA, 33 KV, Subtransient react. 10%
Source I: 5 MVA, 12 KV, Subtransient react. 9%
Source G: 25 MVA, 12 KV, Subtransient react. 12%
Transformer C: 50 MVA, 110/12 KV, 8% react.
Transformer D: 20 MVA, 110/12 KV, 8% react.
Transformer E: 60 MVA, 110/12 KV, 8% react.
Transformer F: 110/33/12 KV
H to M 10% on 25 MVA base.
H to L 8% on 10 MVA base.
M to L 12% on 20 MVA base.
Fault occurs at one-quarter distance D to E, near D.

* Detail A



Equivalent Circuit for Three-winding Transformer

Fig. A-24. System Diagram, Example 4

```
NOFALT
NOMUTL
  8        6.928       0.0       0.0 -10023.4       0.0 -10023.4
  7        6.928       0.0       0.0  -2672.9       0.0  -2672.9
  6        19.05       0.0       0.0 -8751.08       0.0 -8751.08
  2        6.928       0.0       0.0  -2749.3       0.0  -2749.3
  1        6.928       0.0       0.0  -8018.6       0.0  -8018.6
CURSOR  5
SHTCKT
  0  0
  5  6  110 53 50000         55.62         55.62        1.        4
  6  7  110 53 50000     0. 92.31      0. 92.31         1.        2 0
  5  7  110 53 50000     0.280.01      0.280.01         1.        4 0
  5  8  110 53 60000     0.    .08     0.    0.0        1.        1 2
  2  3  110 53 20000     0.    .08     0.    0.0        1.        1 2
  3  1  110 53 50000        .0798      0. .0798         1.        4 1
  3  5  110 13     1     0.   40.0
  2  4  110 13     1     0.   10.0
  4  5  110 13     1     0.   30.0
SYSPAR 50000.
PGMCON  3  1  4
 EXAMPLE PROBLEM #4                      SHORT CIRCUIT ANALYSIS(WESTINGHOUSE)
```

FORTRAN Control Cards

Fig. A-25. Data Card Format, Example 4

```
POWER DISTRIBUTION SYSTEM ANALYSIS PROGRAM (PDSAP)
TAPE 1 PRINTOUT
```

```
EXAMPLE PROBLEM #4
SHORT CIRCUIT ANALYSIS(WESTINGHOUSE)
```

```
**** PROGRAM CONTROL CONSTANTS ****

CON=  3
INP=  1
OUT=  4
CHG= -0
```

```
*** PROGRAM PARAMETER CONSTANTS ***

BASE KVA       FREQUENCY     TEMPERATURE      EARTH RESISTIVITY
50000. KVA      60. HZ       25. DEG. C         100. METER-OHM
```

```
LINEZ SUBROUTINE
ASSEMBLED INPUT LINE DATA  (PER-UNIT)
```

```
CONDUCTOR NO.   1
FROM - TO      RE(Z)         IM(Z)         RE(Z0)        IM(Z0)
  4    5       0.0000        .1240         0.0000        .4339

CONDUCTOR NO.   2
FROM - TO      RE(Z)         IM(Z)         RE(Z0)        IM(Z0)
  3    4       0.0000        .0413         0.0000        .1446

CONDUCTOR NO.   3
FROM - TO      RE(Z)         IM(Z)         RE(Z0)        IM(Z0)
  3    5       0.0000        .1653         0.0000        .5785

TRANSFORMER, FIXED NO.   1
FROM - TO      RE(Z)         IM(Z)         RE(Z0)        IM(Z0)
  3    1      -0.0000        .0798         0.0000        .0798
 TAP     CONEC CODE
1.00000     4
```

```
  TRANSFORMER, FIXED NO.    2
  FROM - TO      RE(Z)           IM(Z)          RE(Z0)          IM(Z0)
    2    7        0.0000          .2000          0.0000           .2000
  TAP      CONEC CODE
1.00000          1

  TRANSFORMER, FIXED NO.    3
  FROM - TO      RE(Z)           IM(Z)          RE(Z0)          IM(Z0)
    5    8        0.0000          .0667          0.0000           .0667
  TAP      CONEC CODE
1.00000          1

  TRANSFORMER, FIXED NO.    4
  FROM - TO      RE(Z)           IM(Z)          RE(Z0)          IM(Z0)
    5    7        0.0000         1.1571          0.0000          1.1571
  TAP      CONEC CODE
1.00000          4

  TRANSFORMER, FIXED NO.    5
  FROM - TO      RE(Z)           IM(Z)          RE(Z0)          IM(Z0)
    6    7        0.0000          .3814          0.0000           .3814
  TAP      CONEC CODE
1.00000          2

  TRANSFORMER, FIXED NO.    6
  FROM - TO      RE(Z)           IM(Z)          RE(Z0)          IM(Z0)
    5    5        0.0000          .2299          0.0000           .2299
  TAP      CONEC CODE
1.00000          4

*****************************************************************************
*                                                                           *
*                        SHORT CIRCUIT INPUT DATA                           *
*                                                                           *
*****************************************************************************

SOURCE IMPEDANCE BUS NO.  1      VOLTS L-N(KV)       6.93      0.00
3-PH FAULT CURRENT(AMPS)       0.00 -8018.50
PH-GND FAULT CURRENT(AMPS )       0.00 -8018.50
FAULT Z(OHMS) -0.0 -0.0:  NEUT Z(OHMS) -0.0 -0.0

SOURCE IMPEDANCE BUS NO.  2      VOLTS L-N(KV)       6.93      0.00
3-PH FAULT CURRENT(AMPS)       0.00 -2749.30
PH-GND FAULT CURRENT(AMPS )       0.00 -2749.30
FAULT Z(OHMS) -0.0 -0.0:  NEUT Z(OHMS) -0.0 -0.0

SOURCE IMPEDANCE BUS NO.  5      VOLTS L-N(KV)      19.05      0.00
3-PH FAULT CURRENT(AMPS)       0.00 -8751.08
PH-GND FAULT CURRENT(AMPS )       0.00 -8751.08
FAULT Z(OHMS) -0.0 -0.0:  NEUT Z(OHMS) -0.0 -0.0

SOURCE IMPEDANCE BUS NO.  7      VOLTS L-N(KV)       6.93      0.00
3-PH FAULT CURRENT(AMPS)       0.00 -2672.30
PH-GND FAULT CURRENT(AMPS )       0.00 -2672.30
FAULT Z(OHMS) -0.0 -0.0:  NEUT Z(OHMS) -0.0 -0.0

SOURCE IMPEDANCE BUS NO.  8      VOLTS L-N(KV)       6.93      0.00
3-PH FAULT CURRENT(AMPS)       0.00-10023.40
PH-GND FAULT CURRENT(AMPS )       0.00-10023.40
FAULT Z(OHMS) -0.0 -0.0:  NEUT Z(OHMS) -0.0 -0.0
```

```
*************************************************************************
*                                                                       *
*        POWER DISTRIBUTION SYSTEM ANALYSIS PROGRAM (PDSAP)             *
*                        TAPE 2 PRINTOUT                                *
*                                                                       *
*************************************************************************


*************************************************************************
*                                                                       *
*             EXAMPLE PROBLEM #4                                        *
*             SHORT CIRCUIT ANALYSIS(WESTINGHOUSE)                      *
*                                                                       *
*************************************************************************

                **** PROGRAM CONTROL CONSTANTS ****

                            CON=  3
                            INP=  1
                            OUT=  4
                            CHG= -0


                *** PROGRAM PARAMETER CONSTANTS ***

   BASE KVA        FREQUENCY       TEMPERATURE       EARTH RESISTIVITY
  50000. KVA        60. HZ          25. DEG. C          100. METER-OHM


*************************************************************************
*                                                                       *
*                 RESULTS OF SHORT CIRCUIT ANALYSIS                     *
*                     ALL VALUES ARE PER-UNIT                           *
*          SYSTEM HAS   8 BUSES. FAULT CODE(SCOP) IS -0 .               *
*             THERE ARE  -0 SUBSYSTEM STUDIES(ISYS).                    *
*                                                                       *
*************************************************************************


*************************************************************************
*                                                                       *
*                  AUTOMATIC SHORT-CIRCUIT STUDY:                       *
*               ENTIRE NETWORK STUDY WILL BE COMPLETED                  *
*               IN 1 PASSES OF SHORT-CIRCUIT PROGRAM.                   *
*                                                                       *
*************************************************************************
```

```
1
                    ****************************
                    * FAULT SUMMARY FOR BUS   1 *
                    *   ZF= ( 0.00, 0.00) P.U.  *
                    *   ZG= ( 0.00, 0.00) P.U.  *
                    ****************************

  THREE-PHASE        PHASE-GROUND       PHASE-PHASE        PH-PH-GROUND
****************   ****************   ****************   ****************
IF(MAG)=  7.0493   IF(MAG)=  5.1393   IF(MAG)=  6.1047   IF(MAG)=  4.0437
X/R=          P    X/R=********       X/R=          R    X/R=********
****************   ****************   EF(A)= 1.0000      EF(A)= 1.2132
                                      EF(B)=  .5000      EF(B)= 0.0000
                                      EF(C)=  .5000      EF(C)= 0.0000
                                      ****************   IF(B)= 6.4307
                                                         X/R(B)=   3.019
                                                         IF(C)=  6.4307
                                                         X/R(C)=   3.019
                                                         ****************

  BUS VOLTAGES        PHASE VOLTAGES
BUS     V(MAG)          A    B    C
  1      0.0000       0.00 1.15 1.16
  3       .2955        .65  .93  .93
  2       .4274        .72  .94  .94
  4       .3593        .69  .93  .93
  5       .5496        .78  .95  .95
  6       .8591        .93  .98  .98
  7       .8749        .92  .98  .98
  8       .6475        .83  .95  .96

  LINE CURRENTS       LINE CURRENTS
LINE      FAULT(I)    FAULT(I) PH-A
  3   1   3.7161          1.8062
  3   2    .6544           .3180
  4   3   1.5309           .7441
  5   3   1.5309           .7441
  5   4   1.5309           .7441
  6   5   1.3464           .6544
  7   5    .2466           .1199
  7   6    .0632           .0307
  8   5   1.4697           .7139
1
```

```
*****************************
* FAULT SUMMARY FOR BUS   2 *
*    ZF= ( 0.00, 0.00) P.U. *
*    ZG= ( 0.00, 0.00) P.U. *
*****************************

  THREE-PHASE        PHASE-GROUND        PHASE-PHASE         PH-PH-GROUND
****************   ****************   ****************    ****************
IF(MAG)=  4.0569   IF(MAG)=  2.1930   IF(MAG)=  3.5173    IF(MAG)=  1.5025
X/R=          R    X/R=********       X/R=          R     X/R=********
****************   ****************   EF(A)= 1.0000       EF(A)= 1.3148
                                      EF(B)=  .5000       EF(B)= 0.0000
                                      EF(C)=  .5000       EF(C)= 0.0000
                                      ****************    IF(B)= 3.5927
                                                          X/R(B)=   4.677
                                                          IF(C)=  3.5927
                                                          X/R(C)=   4.677
                                                          ****************

  BUS VOLTAGES        PHASE VOLTAGES
BUS    V(MAG)          A    B    C
  1       .6703       .88  .97  .97
  3       .5828       .85  .95  .96
  2      0.0000      0.00 1.29 1.29
  4       .6203       .85  .97  .97
  5       .7723       .90  .98  .98
  6       .9164       .97  .99  .99
  7       .9021       .96  .99  .99
  8       .7903       .92  .98  .98

  LINE CURRENTS       LINE CURRENTS
LINE      FAULT(I)    FAULT(I) PH-A
  3   1   1.0334            .3958
  3   2   2.9141           1.0501
  4   3    .9079            .3272
  5   3    .9073            .3272
  5   4    .9079            .3272
  6   5    .7934            .2877
  7   5    .1453            .0527
  7   6    .0375            .0135
  8   5    .8710            .3139
1
```

```
                    *****************************
                    * FAULT SUMMARY FOR BUS    3 *
                    *    ZF= ( 0.00, 0.00) P.U.  *
                    *    ZG= ( 0.00, 0.00) P.U.  *
                    *****************************

  THREE-PHASE        PHASE-GROUND       PHASE-PHASE        PH-PH-GROUND
****************   ****************   ****************   ****************
IF(MAG)=  7.9155   IF(MAG)=  9.3424   IF(MAG)=  6.8548   IF(MAG)= 11.3971
X/R=         R     X/R=********       X/R=         R     X/R=********
****************   ****************   EF(A)= 1.0000      EF(A)=  .7801
                                      EF(B)=  .5000      EF(B)= 0.0000
                                      EF(C)=  .5000      EF(C)= 0.0000
                                      ****************   IF(B)= 9.9139
                                                         X/R(B)=    1.203
                                                         IF(C)=  9.9139
                                                         X/R(C)=    1.203
                                                         ****************

  BUS VOLTAGES        PHASE VOLTAGES
BUS     V(MAG)          A     B     C
  1        .2101       .38   .89   .89
  3       0.0000      0.00   .92   .92
  2        .1860       .36   .88   .88
  4        .0999       .10   .92   .92
  5        .3597       .41   .93   .93
  6        .7997       .84   .95   .96
  7        .7554       .82   .95   .96
  8        .4989       .61   .92   .92

  LINE CURRENTS       LINE CURRENTS
LINE      FAULT(I)    FAULT(I) PH-A
  3    1   2.6329           2.0717
  3    2    .9302            .7319
  4    3   2.1762           1.9339
  5    3   2.1762           1.9339
  5    4   2.1762           1.9339
  6    5   1.9139           1.5060
  7    5    .3506            .2759
  7    6    .0839            .0707
  8    5   2.0979           1.[illegible]28
```

```
                    ******************************
                    * FAULT SUMMARY FOR BUS    4 *
                    *   ZF= ( 0.00, 0.00) P.U.   *
                    *   ZG= ( 0.00, 0.00) P.U.   *
                    ******************************

  THREE-PHASE        PHASE-GROUND       PHASE-PHASE        PH-PH-GROUND
****************   ****************   ****************   ****************
IF(MAG)=  7.1977   IF(MAG)=  6.7726   IF(MAG)=  6.2332   IF(MAG)=  5.3950
X/R=          R    X/R=********       X/R=          R    X/R=********
****************   ****************   EF(A)= 1.0000      EF(A)= 1.0558
                                      EF(B)=  .5000      EF(B)= 0.0000
                                      EF(C)=  .5000      EF(C)= 0.0000
                                      ****************   IF(B)= 7.0054
                                                         X/R(B)=   1.950
                                                         IF(C)=  7.0054
                                                         X/R(C)=   1.950
                                                         ****************

  BUS VOLTAGES        PHASE VOLTAGES
BUS     V(MAG)          A     B     C
  1       .3463        .59   .91   .91
  3       .1725        .35   .94   .94
  2       .3254        .58   .91   .91
  4      0.0000       0.00  1.03  1.03
  5       .3743        .49   .95   .96
  6       .8044        .88   .97   .97
  7       .7703        .86   .97   .97
  8       .5103        .69   .93   .93

  LINE CURRENTS       LINE CURRENTS
LINE       FAULT(I)   FAULT(I) PH-A
  3    1   2.1798           1.3668
  3    2    .7698            .4829
  4    3   4.1734           4.2872
  5    3   1.2248            .7923
  5    4   3.0242           2.4854
  6    5   1.8695           1.1721
  7    5    .3423            .2147
  7    6    .0878            .0551
  8    5   2.0393           1.2786
```

```
*******************************
* FAULT SUMMARY FOR BUS    5 *
*   ZF= ( 0.00, 0.00) P.U.   *
*   ZG= ( 0.00, 0.00) P.U.   *
*******************************

  THREE-PHASE        PHASE-GROUND       PHASE-PHASE        PH-PH-GROUND
****************   ****************   ****************   ****************
IF(MAG)=  8.5500   IF(MAG)=  8.9386   IF(MAG)=  8.2703   IF(MAG)=  8.4009
X/R=         R     X/R=********       X/R=         R     X/R=********
****************   ****************   EF(A)= 1.0000      EF(A)= 1.0602
                                      EF(B)=  .5000      EF(B)= 0.0000
                                      EF(C)=  .5000      EF(C)= 0.0000
                                      ****************   IF(B)= 9.2757
                                                         X/R(B)=   1.959
                                                         IF(C)= 9.2757
                                                         X/R(C)=   1.959
                                                         ****************
```

BUS VOLTAGES BUS	V(MAG)	PHASE VOLTAGES A	B	C
1	.3898	.62	.92	.92
3	.2275	.44	.93	.93
2	.3712	.61	.92	.92
4	.1706	.33	.95	.95
5	0.0000	0.00	1.03	1.03
6	.6871	.80	.95	.95
7	.6336	.77	.95	.95
8	.2174	.51	.90	.90

LINE CURRENTS LINE		FAULT(I)	LINE CURRENTS FAULT(I) PH-A
3	1	2.0339	1.2591
3	2	.7185	.4484
4	3	1.3763	1.3682
5	3	1.3763	1.3682
5	4	1.3763	1.3682
6	5	2.9891	1.8652
7	5	.5476	.3417
7	6	.1404	.0876
8	5	3.2608	2.0347

```
                      *******************************
                      * FAULT SUMMARY FOR BUS    5 *
                      *    ZF= ( 0.00, 0.00) P.U.   *
                      *    ZG= ( 0.00, 0.00) P.U.   *
                      *******************************

  THREE-PHASE          PHASE-GROUND          PHASE-PHASE          PH-PH-GROUND
****************     ****************     ****************     ****************
IF(MAG)= 13.3595     IF(MAG)= 12.0153     IF(MAG)= 11.5693     IF(MAG)= 10.9169
X/R=         R       X/R=********         X/R=         R       X/R=********
****************     ****************     EF(A)= 1.0000        EF(A)= 1.0914
                                          EF(B)=  .5000        EF(B)= 0.0000
                                          EF(C)=  .5000        EF(C)= 0.0000
                                          ****************     IF(B)=12.7922
                                                               X/R(B)=   2.120
                                                               IF(C)= 12.7922
                                                               X/R(C)=   2.120
                                                               ****************

  BUS VOLTAGES          PHASE VOLTAGES
BUS     V(MAG)            A    B    C
  1       .7323         .84  .96  .96
  3       .6619         .80  .95  .95
  2       .7243         .83  .96  .96
  4       .6379         .78  .95  .95
  5       .5623         .74  .94  .94
  6      0.0000        0.00 1.05 1.05
  7       .3474         .61  .92  .92
  8       .6575         .79  .95  .95

  LINE CURRENTS         LINE CURRENTS
LINE       FAULT(I)     FAULT(I) PH-A
  3   1      .9902             .5338
  3   2      .3145             .1886
  4   3      .6024             .3612
  5   3      .6024             .3612
  5   4      .6024             .3612
  6   5     2.4462            1.4667
  7   5      .1957             .1114
  7   6      .9198             .5461
  8   5     1.4272             .8557
```

```
                    ******************************
                    * FAULT SUMMARY FOR BUS    7 *
                    *    ZF= ( 0.00, 0.00) P.U.  *
                    *    ZG= ( 0.00, 0.00) P.U.  *
                    ******************************

  THREE-PHASE        PHASE-GROUND        PHASE-PHASE         PH-PH-GROUND
****************   ****************   ****************   ****************
IF(MAG)=  3.9537   IF(MAG)=  2.1349   IF(MAG)=  3.4282   IF(MAG)=  1.4615
X/R=          R    X/R=********       X/R=          R    X/R=********
****************   ****************   EF(A)= 1.0000      EF(A)= 1.3154
                                      EF(B)=  .5000      EF(B)= 0.0000
                                      EF(C)=  .5000      EF(C)= 0.0000
                                      ****************   IF(B)= 3.5052
                                                         X/R(B)=   4.692
                                                         IF(C)=  3.5052
                                                         X/R(C)=   4.692
                                                         ****************

  BUS VOLTAGES        PHASE VOLTAGES
BUS     V(MAG)          A    B    C
  1       .9073        .97  .99  .99
  3       .8927        .95  .99  .99
  2       .9045        .97  .99  .99
  4       .8740        .95  .99  .99
  5       .8481        .95  .99  .99
  6       .9066        .93  .98  .98
  7      0.0000       0.00 1.29 1.29
  8       .8911        .96  .99  .99

  LINE CURRENTS       LINE CURRENTS
LINE      FAULT(I)    FAULT(I) PH-A
  3   1     .3089           .1111
  3   2     .1092           .0392
  4   3     .2091           .0752
  5   3     .2091           .0752
  5   4     .2091           .0752
  6   5     .1804           .0649
  7   5     .7330           .2635
  7   6   2.1147            .7603
  8   5     .4953           .1781
```

```
                     ******************************
                     * FAULT SUMMARY FOR BUS    8 *
                     *    ZF= ( 0.00,  0.00) P.U.  *
                     *    ZG= ( 0.00,  0.00) P.U.  *
                     ******************************

  THREE-PHASE         PHASE-GROUND        PHASE-PHASE         PH-PH-GROUND
****************    ****************    ****************    ****************
IF(MAG)=  8.5978    IF(MAG)=  5.3475    IF(MAG)=  7.4457    IF(MAG)=  5.0398
X/R=         R      X/R=********        X/R=         R      X/R=********
****************    ****************    EF(A)= 1.0000       EF(A)= 1.2074
                                        EF(B)=  .5000       EF(B)= 0.0000
                                        EF(C)=  .5000       EF(C)= 0.0000
                                        ****************    IF(B)= 7.8591
                                                            X/R(B)=   2.950
                                                            IF(C)=  7.8591
                                                            X/R(C)=   2.950
                                                            ****************

  BUS VOLTAGES        PHASE VOLTAGES
BUS     V(MAG)          A    B    C
  1         .5701     .79  .95  .95
  3         .4557     .73  .94  .94
  2         .5570     .78  .95  .95
  4         .4156     .71  .94  .94
  5         .2954     .65  .93  .93
  6         .7796     .89  .97  .97
  7         .7413     .87  .97  .97
  8        0.0000    0.00 1.15 1.15

  LINE CURRENTS       LINE CURRENTS
LINE      FAULT(I)    FAULT(I) PH-A
  3   1   1.4331            .7053
  3   2    .5063            .2492
  4   3    .9597            .4773
  5   3    .9597            .4773
  5   4    .9597            .4773
  6   5   2.1061           1.0366
  7   5    .3858            .1899
  7   6    .0989            .0487
  8   5   4.4313           2.1810
```

Appendix B. Program Flow Charts

This appendix, updated from the original (Ref 2:56-84), is included to provide a more detailed examination of the program flow and execution. The flow charts do not provide minute details of every program element, but do provide the basic functions performed by major programs and subroutines. The format is also non-standard, and was devised to fit the purpose of this appendix.

A few points about the format are included to aid understanding the figures that follow. Arrows (↓ →) indicate program flow and branch entry locations. The capped line (I) indicates a statement or a group of statements in the program that perform a specific or related function. The text following the capped line summarizes the particular function. Numbers indicate actual program statement numbers. Figures B-1 through B-10 on the following pages show the major program element flow charts.

START

↓

Write Program Title, Read Title Card, Program Control Card; and System Parameter Card; Write program headers on output files (Tape 1 and Tape 2).

↓

Call Input Overlay, (BASIC, 1, 0).

↓

Check error status: If input errors, GO TO 950 (Error input routine). If no errors, continue.

↓

Branch to statement number dictated by CON variable:

→ 100 CON=1. Normal output routine; sorted input line data printed (see statement 100).

→ 20 CON=2. Call Load Flow Overlay (LODFLO, 2, 0). Upon completion, GO TO 100 if no errors, otherwise GO TO 950.

→ 30 CON=3. Call Short Circuit Overlay (SHRTCKT, 3, 0). Check error status upon completion: If errors, GO TO 950. If no errors, GO TO 100.

→ 40 CON=4. Write error statement and GO TO 950. This number reserved for future program use.

Fig. B-1. EXECUTIVE Routine Flow Chart

→ 50 CON=5. Call Load Flow Overlay (LODFLO, 2, 0). Upon completion, check for errors, if none continue, if errors GO TO 950. Call Short Circuit Overlay (SHRTCKT, 3, 0). Check error status upon completion: If errors, GO TO 950; otherwise GO TO 100.

→ 60 CON=6. Write error statement and GO TO 950. This number reserved for future program use.

100
→ Statements 100-101. Write desired data on output file (Tape 1) as dictated by CON and OUT control variables. Rewind appropriate files.

↓

STOP

950
→ Write program error termination statement on output file (Tape 2). Write sorted line tables on output file (Tape 1). Rewind Tape 1.

↓

STOP

END

Fig. B-1. (Cont'd)

START

↓

Check to see of INP value is correct. If not, GO TO 100.

↓

If INP = 0, Call LINDATA Overlay (BASIC 1, 1).

↓

If INP = 1, Call LINEZ Overlay (BASIC 1, 2).

↓

Check if Load Flow is to be performed: If CON=1, or CON=3, RETURN to EXEC program. IF IERR, error status, not equal zero, RETURN.

↓

Call bus data input subroutine (BUSIN).

↓

If errors have been generated by bus input routine, RETURN to EXEC program.

↓

Call Subroutine ORDER to reorder bus list.

↓

RETURN to EXEC

100

→ Write input error statement on output file (Tape 2).

↓

RETURN to EXEC

END

Fig. B-2. INPUT Routine Flow Chart

START

↓

Write appropriate assembled line data header on output file (Tape 1).

↓

210 → Read one record (card) of line data.

↓

Check if last line data record (EB=0). If yes, GO TO 930.

↓

Increment line counters. Check if max. number of lines has been exceeded; if yes, GO TO 855.

↓

If ID, VP or PH equal zero, GO TO 859.

↓

Branch to statement number dictated by ID value:

→ 211 ID=1; Copper, aerial.

→ 212 ID=2; ACSR, aerial.

→ 300 ID=3; Cable, underground, aluminum.

→ 400 ID=4; Cable, underground, copper.

→ 500 ID=5, 6, 7, 8; Transformer (any type).

→ 820 ID=9; Series Capacitor.

→ 830 ID=10; Series Reactor.

211 → Calc. ρ for copper aerial using input temperature; assign F2 constant value; GO TO 214

Fig. B-3. LINDATA Routine Flow Chart

212
→ Calc. ρ for ACSR using input temperature; assign F2 constant value.

↓

214
→ Calc. DC and AC resistance. Determine F1 constant from stranding input or default value. Calc. inductive reactance out to one foot radius, ind. reac. due to conductor spacing, and total ind. reactance. Calc. pos. seq. impedance.

↓

Calc. zero seq. resistance and ind. reactance components. Calc. zero seq. impedance. Check for neutrals, if none GO TO 900.

230
Initialize variables TC, TMXX, TPI, VS, TMNN for adjusting zero sequence impedance values due to neutrals. Dummy variables used in guide are defined as follows: STRG=TMXX, NG=TC, DMCG=TMNN, DMGG=TPI, SG=VS.

235
After initial values for variables are established, repeat statements 214-217 for ac resistance and new XA value.

240
Return from 217 and calculate new zero sequence impedance adjusted for neutrals.

↓

GO TO 900

Fig. B-3. (Cont'd)

Using table look-up (based on cable size), assign pos. and zero seq. impedances for aluminum underground cables.

↓

Statement numbers 302-339; table of alum. UG cable impedances.

↓

GO TO 900

Using table look-up (based on cable size), assign pos. and zero seq. impedances for copper cable.

↓

Statement numbers 402-440; table of copper UG cable impedances.

↓

GO TO 900

Increment transformer counter (NOTR). Check if max. number transformers has been exceeded; if yes, GO TO 857.

↓

Branch to statement number dictated by ID (type of transformer).

→ 858 ID=1, 2, 3, 4, 9, 10; error.

→ 860 ID=5, 6, 7 and C greater than 5; error.

→ 518 ID=5; fixed transformer.

Fig. B-3. (Cont'd)

→ 600 ID=6; autotransformer.

→ 700 ID=7; Load tap-changer.

→ 800 ID=8; phase-shifter.

518
→ Calc. fixed trans. pos. and zero seq. impedances based on size (KVA), and high-side voltage rating (KV).

↓

Statement numbers 519-581; fixed transformer impedance table/equations; GO TO 901.

600
→ Calc. pos. and zero seq. impedances for autotrans; leakage impedance value is determined by fixed trans. routine (enter at statement 519).

↓

Statement numbers 649-667; autotrans. impedance equations; GO TO 901.

700
→ Increment LTC counter (NOLTC); If max. no. of LTC's has been exceeded, GO TO 854.

↓

Calc. pos. and zero seq. impedances; leakage impedance value is determined from fixed trans. routine (enter at statement 519); GO TO 901.

800
→ Increment phase-shifter counter (NOPH); If max. no. of phase-shifters has been exceeded, GO TO 856.

Fig. B-3. (Cont'd)

Calc. pos. and zero seq. impedances; leakage impedance is determined by fixed trans. routine (enter at statement 550).

↓

Statement numbers 801-805; phase-shifter impedance equations. GO TO 901.

820
→ Calc. pos. and zero seq. impedance for series capacitor. GO TO 901.

830
→ Calc. pos. and zero seq. impedance for series reactor. GO TO 901.

850
→ Statement numbers 850-860; error statements written on output file (Tape 2); error counter incremented (IERR).

↓

GO TO 210 or RETURN

900
→ Set S=0 (for per unit calculation); Calc. frequencey adjusting factors (for cable only).

↓

901
→ Check to see that both pos. and zero seq. impedances are not zero. If yes, GO TO 853. Call PERUNIT to convert values to per-unit.

↓

902
Statement numbers 902-929; write assembled line data on output file (Tape 1) with appropriate data header (conductor, trans. etc.); store data in appropriate tables.

↓

Fig. B-3. (Cont'd)

GO TO 210

930
→ If there are any input errors (IERR $\neq$ 0), RETURN to INPUT program.

↓

Call subroutine LSORT to sort line, transformer, and phase-shifter tables (after all line records are input).

↓

945
Statement numbers 945-950; Calc. number of connections for each bus, and store in CONEC array; calc. no. of connections (if any) to ref. bus (IZ); Determine no. of buses in system (not including ref. bus) (NBUS).

↓

RETURN

END

Fig. B-3. (Cont'd)

START

↓

Write appropriate data headers on output files (Tape 1 and Tape 2).

↓

10 → Read one data record (card).

↓

Check for last time data record (EB = 0); If last record, GO TO 930. If ID = 5, 6, 7 and C greater than 5, GO TO 800.

↓

Increment line counter; if maximum no. of lines is exceeded, GO TO 855. If VP, ID, or PH equal 0, GO TO 858.

↓

Check for zero impedances (pos. and neg. sequence); IF both zero, GO TO 853.

↓

Branch to appropriate statement number based on value of ID:

↓

→ 20 ID=5, 6, 7, 8; (Transformer routine).

→ 30 ID=9; (series capacitor routine).

→ 35 ID=10; (series reactor routine).

Increment conductor counter (line is aerial or cable).

↓

Fig. B-4. LINEZ Routine Flow Chart

Assign pos. and zero seq. impedances and multiply by line length. If zero seq. not specified, zero seq. equal to 2.7 or 3.5 times pos. sequence determined by presence or absence of neutrals.

↓

GO TO 900

20 → Increment transformer counter; if max. no. of transformers exceeded, GO TO 857.

↓

Branch to statement number based on ID:

→ 800 ID=1, 2, 3, 4, 9. or 10 (error).

→ 21 ID=5; fixed transformer; increment fixed transformer counter and assign Z and ZØ; GO TO 900.

→ 23 ID=7; LTC; increment LTC counter; if max. no. of LTC's exceeded, GO TO 854; assign Z and ZØ. GO TO 900.

→ 24 ID=8; Phase-shifter; increment phase-shifter counter; if max. no. of phase-shifters exceeded, GO TO 856; assign Z and ZØ. GO TO 900.

30 → Increment capacitor counter; assign Z and ZØ; GO TO 900.

35 → Increment reactor counter; assign Z and ZØ; GO TO 900.

Fig. B-4. (Cont'd)

800
→ Error statememts.

900
→ Statements 900-920. Write assembled data on output file (Tape 1) with appropriate header, in ohms or per-unit values; convert data to per-unit values if necessary.

↓

GO TO 10

930
→ Statements 930-960. If there are input errors (IERR ≠ 0) RETURN. Sort line, transformer, and phase-shifter tables into order by ascending bus numbers (call subroutine LSORT). Do 950 Loop: Calculate no. of connections for each bus and store in CONEC array; count no. of connections to ref. bus (if any) and save as IZ: Determine no. of buses in system (not including ref. bus) and save as NBUS.

↓

RETURN

END

Fig. B-4. (Cont'd)

START

↓

Write load-flow header on output file (Tape 2).

↓

Statements 1-7. Initialize NA array. DO 5 Loop: Calc. array of B off-diagonal elements (DU) and dummy connection array (NA); DO 7 Loop: Calc. array of B′ diagonal elements (BDIA).

↓

DO 100 Loop: Triangulate B′ matrix; Select row no. (IRW) from reordered bus list (NB); Calc. Diag. element (DBP) and assign value to row index pointer (IUBP); If last bus in list, GO TO 100. Note: Slack bus is bypassed in this routine.

↓

DO 10 LOOP: Forms list of row no.'s (IDUM) that will be affected by elimination of IRW.

↓

DO 15 LOOP: Forms array of upper-triangle elements of IRW (UBP) and list of column identifiers (JBP) for each element.

↓

DO 50 LOOP: Eliminated IRW by standard matrix row reduction.

↓

100 → End of B′ Triangulation.

↓

Fig. B-5. Load Flow (FDLFLOW)

DO 105 Loop: Calc. array of B´´ off-diag. elements (DU) and dummy connection array (NA); DO 107 Loop: Calc. array of B´´ diag. elements (BDIA).

↓

DO 200 LOOP: Triangulate B´´ matrix; Select row no. (IRW) from reordered bus list (NB); Calc. Diag. element (DBPP) and assign value to row index pointer (IUBPP); if last bus in list, GO TO 100. Note 1: Slack bus and PV buses are bypassed in this routine. Note 2: interior loops perform same functions as in DO 100 Loop above.

↓

200 → End of B´´ Triangulation.

↓

Restore dummy NA array; initialize LIST array.

↓

211 → Entry point for ΔP - Δθ solution routine.

↓

DO 250 Loop: Calc. ΔP/V array (DLP) for each bus in B´; If |ΔP/V|> tolerance, set KP = 1.

↓

If KP = 0 (Converged) GO TO 400. If max. no. of iterations has been exceeded, GO TO 500.

↓

DO 270 Loop, DO 275 Loop and DO 285 Loop: Direct soln. of [ΔP/V] = [B´]·[Δθ] equation for [Δθ]. Note: Matrix operations performed on DLP array transform it into the Δθ solution array.

Fig. B-5. (Cont'd)

DO 290 Loop: Updates bus angle array (ANG) by adding Δθ for each bus.

↓

Increment ΔP-Δθ iteration counter.

↓

291 → Entry point for ΔQ-ΔV solution routine.

↓

DO 350 loop: Calc. ΔQ/V array (DLQ) for each bus in B´´; If |ΔQ/V|> tolerance KQ = 1.

↓

IF KQ = 0 (Converged) GO TO 401. If max. no. of iterations has been exceeded, GO TO 500.

↓

DO 370 loop, DO 375 loop, and DO 385 loop: Direct solution of ΔQ/V = [B´´] [ΔV] equation for [ΔV]. Note: Matrix operations performed on DLQ array transform it into the ΔV solution array.

↓

DO 390 and DO 388 loops: Update bus voltage magnitude array (V) by adding ΔV for each bus.

↓

Increment ΔQ-ΔV iteration counter.

↓

Call subroutine LIMIT (Check for PV bus Q-limit violations.)

↓

GO TO 211

Fig. B-5. (Cont'd)

400
→ If KQ = 0 (ΔQ-ΔV is converged) GO TO 450; otherwise GO TO 291.

↓

401
→ IF KP = 0 (ΔP-$\Delta\theta$ is converged) GO TO 450; otherwise GO TO 211.

↓

450
→ Write convergence data on output file (Tape 2); Calc. Slack bus power.

↓

453
→ If line flows are not to be calc. (OUT = 6), GO TO 456.

↓

Calc. and write line flows on output file (Tape 2).

↓

456
→ Statements 456-461. Convert ANG array from radian units to degrees. Write (Tape 2), summarized data for each bus.

↓

GO TO 570

500
→ Statements 500-520. Write non-convergence data header on output file (Tape 2), and non-convergence table with Delta P and Delta Q.

570
→ If value of NLC, automatic load change, is zero, GO TO 999 and RETURN.

↓

Fig. B-5. (Cont'd)

580
Statements 580-602 contain the load change routine. Read data cards for load changes and write load change information on Tape 2. Number of bus changes is NC. NCC is number of times load change routine used. Data read in as in BUSIN routine with variables IDB, BUSNAME, V, ANG, P, Q, QMIN, QMAX. Arrays are adjusted with new information. Re-calculate load flow results by starting at 210 again.

900
Statements 900-980 are error messages.

999
RETURN.

END

Fig. B-5. (Cont'd)

START

↓

DO 100 LOOP: Loops through all buses to find PV buses; calculated Q for each PV bus; Bypasses rest of routine if QMAX and QMIN are both zero.

↓

Check if QMIN or QMAX have been exceeded; if not, GO TO 100.

↓

20 → QMAX exceeded; calculate QMAX - $Q_{calc.}$ (DEL).

↓

If Q violation for this bus has already been written on output file, GO TO 50.

↓

Calculate percent over; write on output file (Tape 2); GO TO 50.

↓

25 → QMIN exceeded; calculate QMIN - $Q_{calc.}$ (DEL).

↓

If Q violation for this bus already been written on output file, GO TO 50.

↓

Calculate percent over; write on output file (Tape 2).

↓

50 → If magnitude DEL $\leq$ .01, GO TO 100.

↓

If sensitivity factor has already been calculated (SK(I)$\neq$0) for this bus, GO TO 90.

↓

Fig. B-6. LIMIT Subroutine Flow Chart

DO 60, DO 51, and DO 61 loops: form missing column of [B´´] corresponding to $i^{\underline{th}}$ PV bus (DU).

↓

DO 70, DO 65, DO 75, and DO 80 loops: Calculate sensitivity factor for $i^{\underline{th}}$ PV bus.

↓

90 → Calculate incremental voltage change for $i^{\underline{th}}$ PV bus (DV).

↓

DO 91 loop: check if LTC branch is connected to $i^{\underline{th}}$ PV bus, if yes GO TO 92.

↓

Calculate adjusted bus voltage at $i^{\underline{th}}$ PV bus (NO LTC's).

↓

GO TO 100

92 → Calculate new tap ratio (TNEW).

↓

Check if max. or min. tap limits are exceeded; if yes, set tap ratio at appropriate limit and adjust $i^{\underline{th}}$ PV bus voltage; If not, GO TO 96.

↓

GO TO 100

96 → Calculate nearest physical discreet tap setting (function DISCRET).

↓

Fig. B-6. (Cont'd)

100
→ I End of loop.

↓

RETURN

END

Fig. B-6. (Cont'd)

START

↓

Read short circuit control card. If not in proper format GO TO 912. Write header for input data.

↓

DO 7 loop: Initialize DLP, DLQ and Na arrays. NA is equal to CONEC.

↓

If there are no transformers in line data, GO TO 51.

↓

DO 50 Loop: Checks each transformer connection code to see if any lines to ref. (zero sequence) should be added to line tables (from SB or EB or both); Also puts line of very high impedance between two buses if no zero sequence path exist.

↓

51 → Read current source control (CURSOR) card indicating how many source impedance data cards will be read (IREF): if IREF = 0, GO TO 65.

↓

DO 60 Loop: Reads in source impedance data, one current data card at-a-time; calculates equivalent pos. and zero sequence source impedances, and stores data in appropriate line tables; adjusts CONEC array for each added line.

↓

Fig. B-7. Short Circuit (FAULT) Routine

65

→ All lines have been added to line tables; call subroutine LSORT to sort line data into order by ascending bus no.

↓

Update NA array (= CONEC) and IZ (no. of lines to ref.)

↓

DO 76 Loop: Forms a feasible ordering of bus list for impedance matrix building algorithm; Stores reordered bus list in LIST array, and stores list of line table entry numbers in JBP array.

↓

Check to see of no. buses in LIST = NBUS, and no. lines in JBP = no. lines in system. If not equal, GO TO error routine.

↓

Read mutual coupling control (NOMUTL) card indicating how many lines with mutual coupling are to be read in (NOMU); If NOMU = 0, GO TO 77; If NOMU > 25, GO TO 903, error routine.

↓

Read mutual coupling data into proper storage tables.

↓

77

→ Read fault impedance header (NOFALT) card; If no. of buses (NFT or NOFALT) is zero, GO TO 84.

↓

Fig. B-7. (Cont'd)

Calculate base impedance (ZB) from voltage and phase info. input on header card; Determine how many data cards must be read to input NOFALT number of buses. (NOFALT/26); Read in bus list and store fault impedance as real (DLP) and imaginary (DLQ) components.

↓

84 Check if load-flow bus voltages are to be used for fault calc. and if load-flow converged. Set fault bus voltage array (EBUS) accordingly.

↓

90 Write short-circuit header on output file (Tape 2).

↓

If short circuit analysis is to be accomplished "automatically" (ISYS = 0), GO TO 100.

↓

Set subsystem counter (ICOUNT) equal to ISYS.

↓

95 → If ICOUNT = 0, RETURN control to EXEC; otherwise continue with next subsystem study.

↓

Calc. IOUT for subsystem header (IOUT = subsystem study number).

↓

Read subsystem control (NOBSYS) card indicating how many buses are in this subsystem study (NBS); if NBS > 50, GO TO 904.

↓

Fig. B-7. (Cont'd)

Write subsystem header on output file (Tape 2), and read subsystem bus list.

↓

GO TO 105

100 → DO 101 Loop: Sets up dummy bus list (NB) for automatic short-circuit study.

↓

Calc. IOUT for automatic header (IOUT = no. of passes of short-circuit program to complete network study (NBUS/50); Write header on output file (Tape 2), and set bus count.

↓

105 → Entry point for bus building algorithm (initial pass only for auto); re-entry for subsystem studies.

↓

106 → Call BUS; subroutine BUS is positive sequence Z-building algorithm; re-entry point for subsequent passes of auto. short-circuit study.

↓

If error status is not OK (IERR ≠ 0), RETURN.

↓

Call BUSØ; subroutine BUSØ is the zero sequence Z-building algorithm, with mutual coupling handled by subroutine MUTEST.

↓

If error status is not OK (IERR ≠ 0), RETURN.

↓

Fig. B-7. (Cont'd)

DO 200 Loop: Calculates fault currents for buses in subsystem or network segment; IRW is faulted bus no., and F and G are fault and neutral impedances, respectively for faulted bus.

↓

If bus is single-phase only (IPHASE (IRW = 1) GO TO 132.

↓

Calculate 3∅ fault for bus IRW (AMPA); Calculate X/R ratio for fault current (XR); calculate bus voltages if desired, otherwise GO TO 132.

↓

132 → Calculate phase-ground fault for bus IRW (AMPA); Calculate X/R ratio (XRLG) from equivalent impedance (ZZE); calculate voltages and line currents if desired; otherwise GO TO 149.

↓

149 → Check if phase-phase and phase-phase-ground faults are to be calculated (SCOP = 0 or 1); if not, GO TO 160.

↓

If bus is single-phase, GO TO 170.

↓

Calculate phase-phase fault (AMPA) and X/R ratio (XRLL) for bus IRW; Calculate and store faulted bus voltage summaries only.

↓

Fig. B-7. (Cont'd)

Calculate phase-phase-ground fault current (AMPA) and X/R ratio (XRLLG); Also calculate fault currents in each faulted phase (FAULTLB) and (FAULTLC) and associated X/R ratios (XRLB and XRLC); Calc. voltage summary for faulted bus only.

↓

150 → Write fault summaries for bus IRW on output file (Tape 2); all fault types, and voltage summaries if desired.

↓

160 → Write 3∅ and 1∅ - gnd. fault summaries <u>only</u> on output file (Tape 2), voltage summaries and line currents if desired.

↓

GO TO 200

170 → Write 1∅ - gnd. fault summary only on output file (Tape 2), voltage summaries and line currents if desired.

↓

200 → End of Loop.

↓

Decrement subsystem counter (ICOUNT); Calculate new value for M (automatic study segment list position); Determine bus count (NBS) for next pass of automatic study.

↓

If study is <u>not</u> automatic (ISYS $\neq$ 0), GO TO 95.

↓

Check if automatic study is complete (M = 0); if yes RETURN.

↓

Fig. B-7. (Cont'd)

```
                    GO TO 106
900-950
→ I Write statements for errors.
                      ↓
                    RETURN

                     END
```

Fig. B-7. (Cont'd)

START

DO 9, DO 10, DO 11, DO 12 initialize arrays ZDIA, IUBP, ZC, ZBUS, NA.

DO 100 Loop: Forms the pos. sequence bus impedance matrix, one line at-a-time, according to order stored in JBP; L is the position of the line data in the sorted line tables; If pos. sequence Y is zero (transformer connection), line is bypassed, although bus connection count (NA) is reduced; algorithm used is detailed in Brown (Ref 1:28-48). IUBP is last of bus numbers in subsystem.

If line has one node reference, GO TO 25.

5 Entry for branch element routine (no nodes ref.); GO TO 90.

15 Entry for loop-closing element routine (no nodes ref.); GO TO 80.

25 Entry for lines with one node the reference; If loop closing, GO TO 30.

Add branch (one node ref.) routine; GO TO 90.

Fig. B-8. BUS Subroutine Flow Chart

30
→ Entry for loop-closing (one node ref.) routine.

↓

80
→ Eliminate loop axis by Kron reduction (DO 84 and DO 85 Loops); GO TO 90.

↓

88
→ Re-entry for lines with zero admittance; assign L1 and L2.

↓

90
→ Network reduction routine; connection count for buses on each end of line is reduced; If no more connections are to be processed (NA (XX) = 0), and the bus is not in the area of study, it is eliminated (subroutine SWAP); After a bus is swapped out, the network bus count is decremented by one.

↓

100
→ End of loop.

↓

RETURN

End

Fig. B-8. (Cont'd)

START

↓

DO 1, DO 9, DO 11 initialize arrays IUBP, ZODIA, ZC, NA.

↓

DO 100 Loop: Forms the zero sequence bus-impedance matrix; one line at-a-time in the order stored in JBP array; L is the position of the line data in the sorted line tables. Mutual coupling is handled by subroutine MUTEST; Details in Brown (Ref 1:80-95).

↓

If line has one node reference, GO TO 50.

↓

6 → Entry for branch element (no nodes ref.) routine.

↓

Check for mutual coupling (Call MUTEST); if no mutual coupling (IROW = 0), GO TO 20.

↓

Add branch with mutuals; DO 7 and DO 10 loops add branch with mutuals; function OFFDIAG returns the complex value = $[Y_{pr-rs}]\ [Z_{rk}-Z_{sk}]$. Function DIAG computes $[Y_{pq-rs}]\ [Z_{rq}-Z_{sq}]$; GO TO 90.

↓

20 → Add branch with no mutuals; DO 21 and DO 24 loops add branch with no mutuals; GO TO 90.

↓

25 → Line is loop (no nodes ref.).

↓

Fig. B-9. BUSØ Subroutine Flow Chart

Check for mutual coupling, (Call MUTEST); if no mutual coupling (IROW = 0) GO TO 41.

↓

Add loop with mutuals; DO 26 and DO 30 Loops add loop with mutuals; as above, OFFDIAG computes $[Y_{pq-rs}]$ $[Z_{rk}-Z_{sk}]$, and DIAG computes $[Y_{pq-rs}]$ $[Z_{r-loop}-Z_{s-loop}]$; GO TO 80.

↓

41 → Add loop with no mutuals; DO 42 and DO 45 loops add loop element with no mutuals; GO TO 80.

↓

50 → Entry for line element with one node the ref; if loop-closing, GO TO 60.

↓

Add branch with one node ref; GO TO 90.

↓

60 → Line element is loop closing; add loop without mutuals (one node ref.)

↓

80 → Eliminate loop axis by Kron reduction (DO 84 and DO 85 loops).

↓

90 → Network reduction routine; connection count for buses on each end of line is decremented; If no more connections are to processed (NA (XX) = 0), and the bus is not in the subsystem study area, it is eliminated by subroutine SWAPZØ; If swapped out, the remaining net-

Fig. B-9. (Cont'd)

work bus count is decremented.

100

End of loop.

RETURN

END

Fig. B-9. (Cont'd)

START

↓

DO 10 loop: Determines if a line is coupled with any other line in system (scans LA, LB, LR, and LS arrays). If not mutually coupled, RETURN with IROW = 0.

↓

11-16

Determines if line to which mutually coupled is already in system; if not, RETURN with IROW = 0.

↓

21

→ Add new line to mutual building tables.

↓

DO 80 loop: Constructs the mutual impedance coupling matrix for all lines in the system coupled to the new line (detailed in Ref 1:80-95); The DO 50 loop is a searching routine to locate the lines in the mutual building table that are coupled to the new lines.

↓

Call CPLXINV to invert the impedance coupling matrix to obtain the addmittance coupling matrix.

↓

RETURN

END

Fig. B-10. MUTEST Subroutine Flow Chart

Appendix C. Program Variables

This appendix was developed to further document the PDSAP program. All variables and arrays listed in the COMMON statements are indicated as to the overlay source and other overlays where used. Tables contain the variables or arrays listed by COMMON block. Each table lists the source overlay and a brief explanation of the significance of the variable or array. Additionally, figures depict the data flow from the source overlay to the other overlays. When COMMON variables are not used outside the source overlay, the variable is omitted in the corresponding figure. For this reason, there is no figure for the COMMON ZERO arrays or COMMON ZCONST variables as all are unique to the source overlay.

Variables and arrays not listed in this appendix are unique to each overlay and are traceable to their origin with considerably less effort then the COMMON variables.

Table C-I.

Common COMA Variables

Variable	Overlay Source	Definition/Use/Comments
BKVA	Basic,0,0	Base KVA
BKVA1	Basic,0,0	Base KVA
CHG	Basic, 0,0	Change, not used presently.
CON	Basic, 0, 0	Program control, selects program functions to be used.
F	Basic,0,0	Frequency
INP	Basic,0,0	Input, selects LINEZ or LINDATA routines
ISYS	Shrtckt,3,0	Number of subsystems in short circuit routine
LODOP	Basic,0,0	Used as index in Subroutine LIMIT.
MAXLTC	Basic,0,0	Maximum number of Tap Changing Under Load transformers.
MAXPH	Basic,0,0	Maximum number of phase shifting transformers
MAXTR	Basic,0,0	Maximum number of transformers allowed.
NMAX	Basic,0,0	Number of lines allowed times 2.
OUT	Basic,0,0	Output, controls output printouts.
SCOP	Shrtckt,3,0	Short circuit control, selects base voltages and type faults.
T	(1)Basic,0,0 (2)Lodflo,2,0	(1)Temperature (2)Transformer Tap Setting

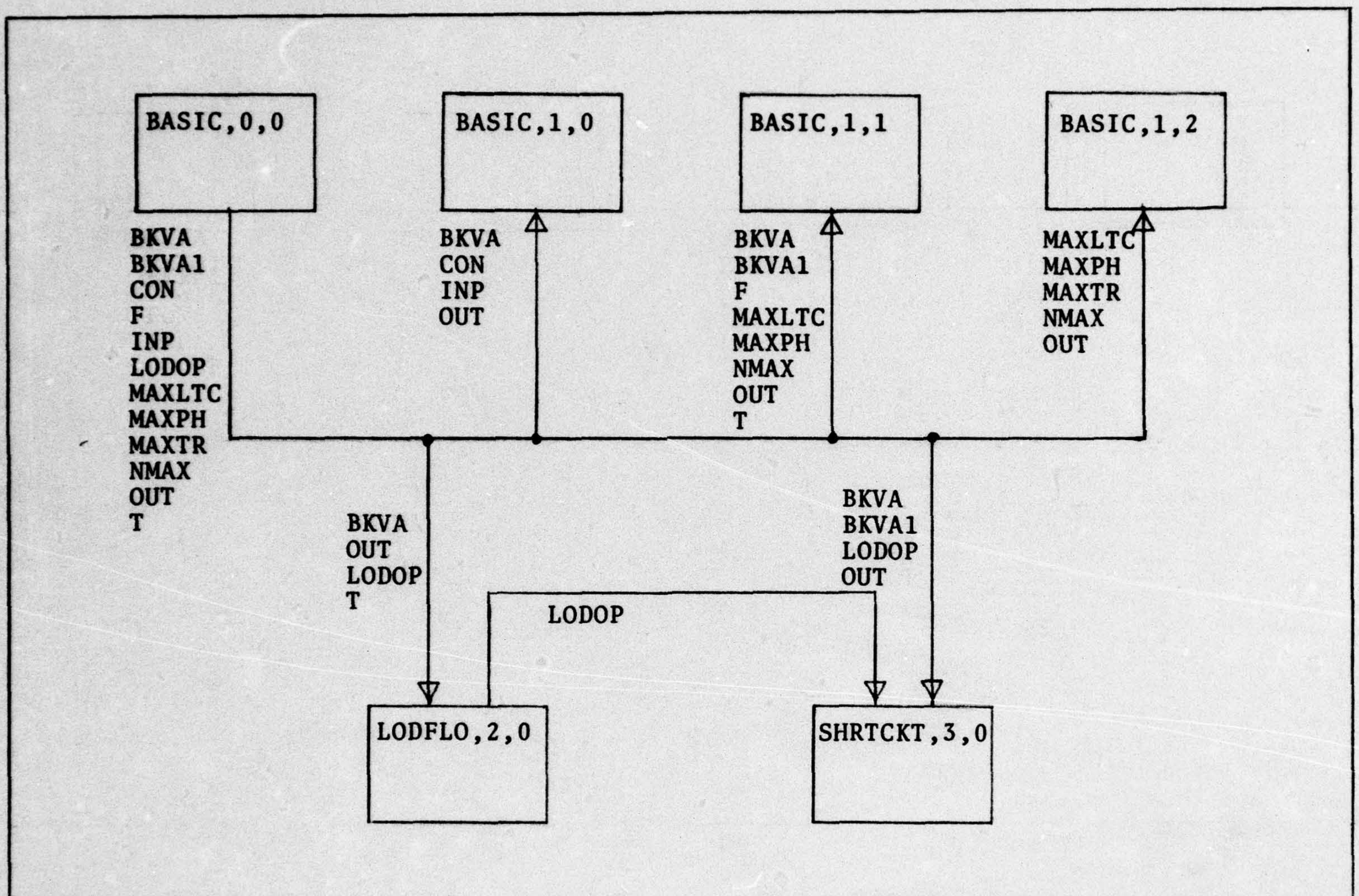


Fig. C-1. COMMON COMA Variables and Data Flow

Table C-II.

Common COMB Arrays

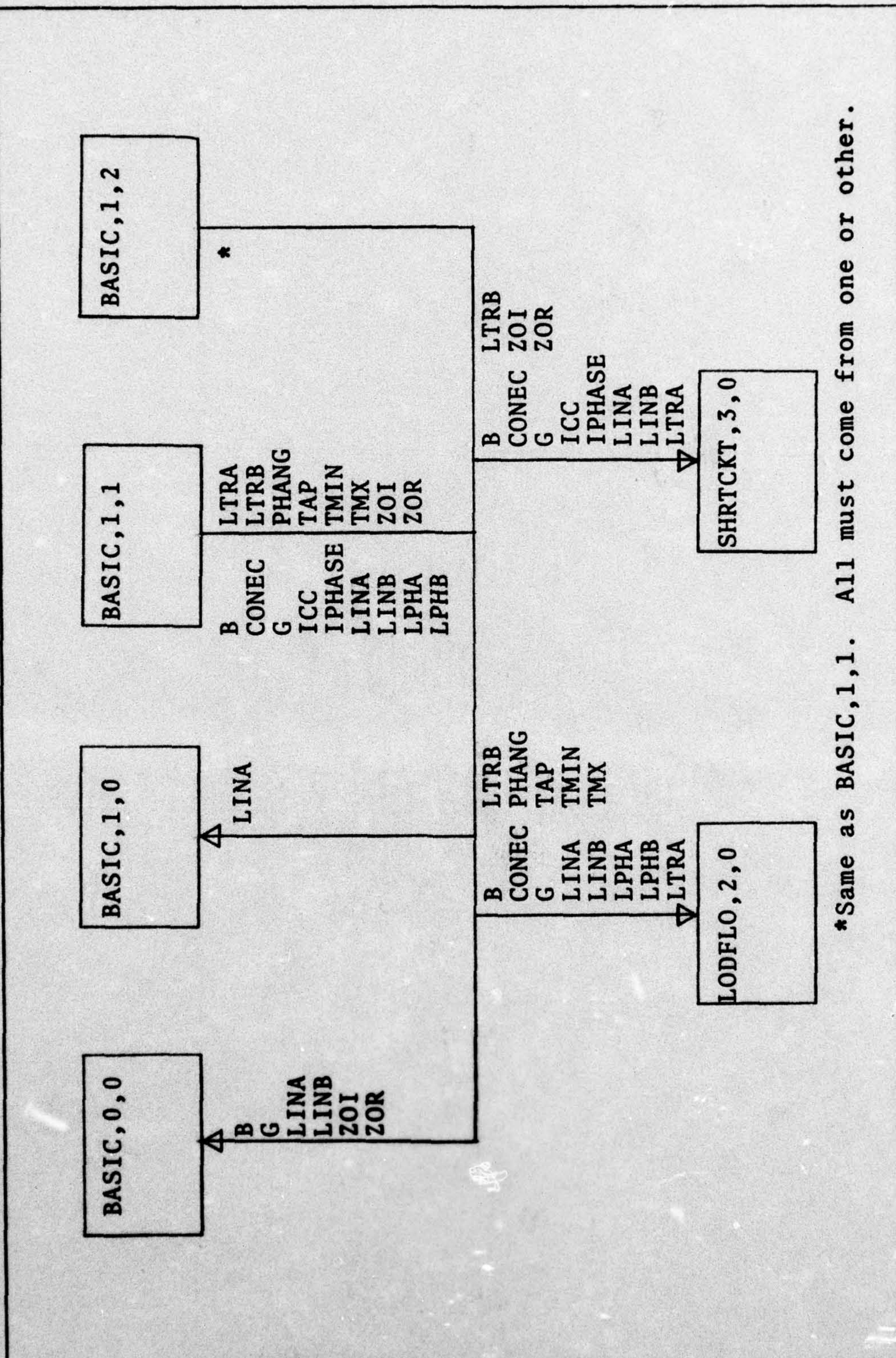
Array(Size)	Overlay Source	Definition/Use/Source
ANG(250)	Basic,1,0and/or Shrtckt,3,0	Bus numbers.
B(1450)	Basic,1,1 or Basic,1,2	Real part of 1/Z, line element susceptance.
BDIA(250)	Lodflo,2,0	Diagonal elements of B´ matrix.
BUSNAME(250)	Basic,1,0 or Shrtckt,3,0	Alphanumeric name of bus.
CONEC(250)	Basic,1,1 or Basic1,2	Number of connections for each bus.
DBP(250)	Lodflo2,0	1/BDIA in triangulation of the B´ matrix.
DBPP(250)	Lodflo2,0	1/BDIA in triangulation of the B´ matrix.
DLP(250)	Lodflo,2,0 (1) Shrtckt,3,0 (2)	Delta P array. Real part of ZF in p.u.
DLQ(250)	Lodflo,2,0 (1) Shrtckt,3,0 (2)	(1) Delta Q array. (2) Img. part of ZF.
G(1450)	Basic,1,1 or Basic,1,2	Real part of 1/Z, line element admittance.
IBUS(250)	Basic,1,0 and/or Shrtckt,3,0	Bus number array.
ICC(250)	Basic,1,1 or Basic,1,2	Transformer code, C + IADD.
IPHASE(250)	Basic,1,1 or Basic1,2	Bus phase array.
IUBP(250)	Lodflo,2,0 (1) Shrtckt,3,0 (2)	(1) Index of first elements of B´ matrix. (2) List of bus numbers for subsystem.

Table C-II. (Cont'd)

Array(Size)	Overlay Source	Definition/Use/Source
IUBPP(250)	Lodflo,2,0	Used in triangulation of the B´´ matrix.
JBP(3000)	Lodflo,2,0 (1) Shrtckt,3,0 (2)	(1) List of solumn identifiers for B´ matrix. (2) List of sorted line table entry numbers.
JBPP(3000)	Lodflo,2,0	List of column identifiers for B´´ matrix.
LINA(1450)	Basic,1,1 or Basic,1,2	End bus. Determined by second bus number.
LINB(1450)	Basic,1,1 or Basic,1,2	Start bus. Determined by first bus number.
LIST(250)	Basic,1,0 and/or Shrtckt,3,0	Used to form re-ordered bus lists.
LPHA(50)	Basic,1,1 or Basic,1,2	End bus for phase-shifter transformers.
LPHB(50)	Basic,1,1 or Basic,1,2	Start bus for phase-shifter transformers.
LTRA(250)	Basic,1,1 or Basic,1,2	SB of transformer, reactor or capacitor.
LTRB(250)	Basic,1,1 or Basic,1,2	End bus of transformer, reactor or capacitor.
Q(250)	Basic,1,0 or Shrtckt,3,0	Reactive power array.
QMAX(250)	Basic,1,0 or Shrtckt,3,0	QMX/BKVA or QMAXN.
QMIN(250)	Basic,1,0 or Shrtckt,3,0	QMN/BKVA or QMINN.
P(250)	Basic,1,0 or Shrtckt,3,0	Real power array.
PHANG(50)	Basic,1,1 or Basic,1,2	Phase angle for phase shifter transformers.

Table C-II. (Cont'd)

Array(Size)	Overlay Source	Definition/Use/Source
TAP(250)	Basic,1,1 or Basic,1,2	Initial setting of tap on transformers.
TMIN(250)	Basic,1,1 or Basic,1,2	Minimum transformer tap setting, in p.u.
TMX(250)	Basic,1,1 or Basic,1,2	Maximum tap setting of transformer.
UBP(3000)	Lodflo,2,0 (1) Shrtckt,3,0 (2)	(1) Upper triangular elements of B´ matrix. (2) Absolute value of voltage for buses in subsystem.
UBPP(3000)	Lodflo,2,0	Upper triangular list of elements for B´´ matrix.
V(250)	Basic,1,0 Shrtckt,3,0	Bus voltage array.
ZOI(1450)	Basic,1,1 or Basic,1,2	Imaginary part of zero sequence impedance.
ZOR(1450)	Basic,1,1 or Basic,1,2	Real part of zero sequence impedance.



*Same as BASIC,1,1. All must come from one or other.

Fig. C-2. COMMON COMB Arrays and Data Flow

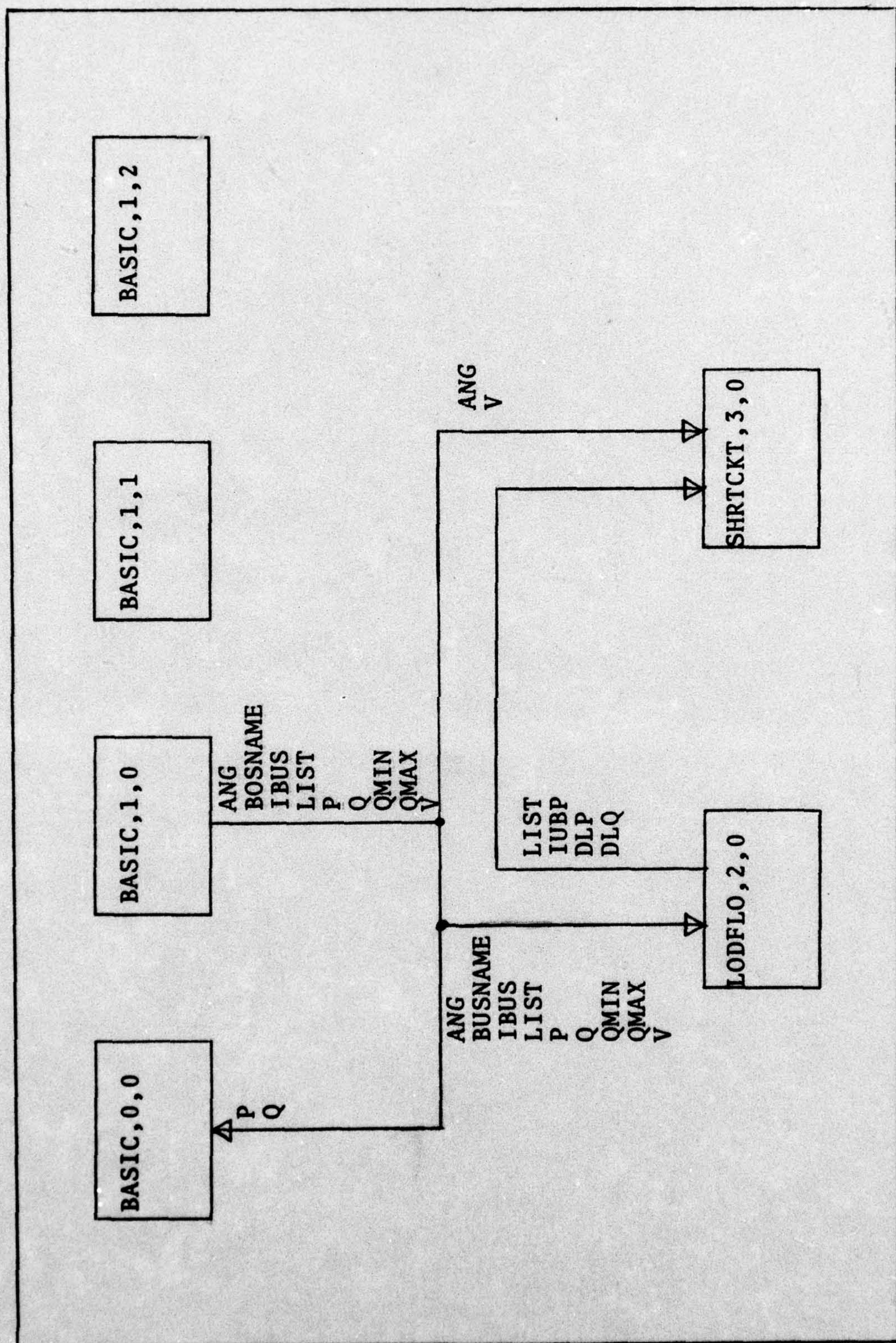


Fig. C-2. (Cont'd) COMMON COMB Arrays and Data Flow

Table C-III.

Common COMC Arrays

Array(Size)	Overlay Source	Definition/Use/Comments
DU(1000)	Lodflo,2,0 (1) Shrtckt,3,0 (2)	(1) Array of B′ matrix off diagonal elements. (2) Array of bus voltages.
IDB(250)	Basic,1,0 and/or Lodflo,2,0 and/or Shrtckt,3,0	Bus type (ID).
JCOL(1000)	Basic,0,0 and Lodflo,2,0	List of end bus numbers.
NA(250)	Basic,0,0 and Lodflo,2,0 and/or Shrtckt,3,0	Number of connections to each bus. Used as dummy array in each routine.
NB(250)	Basic,0,0 (1) Shrtckt,3,0 (2)	(1) Used as reordered bus list. (2) List of buses in subsystem, NBS.

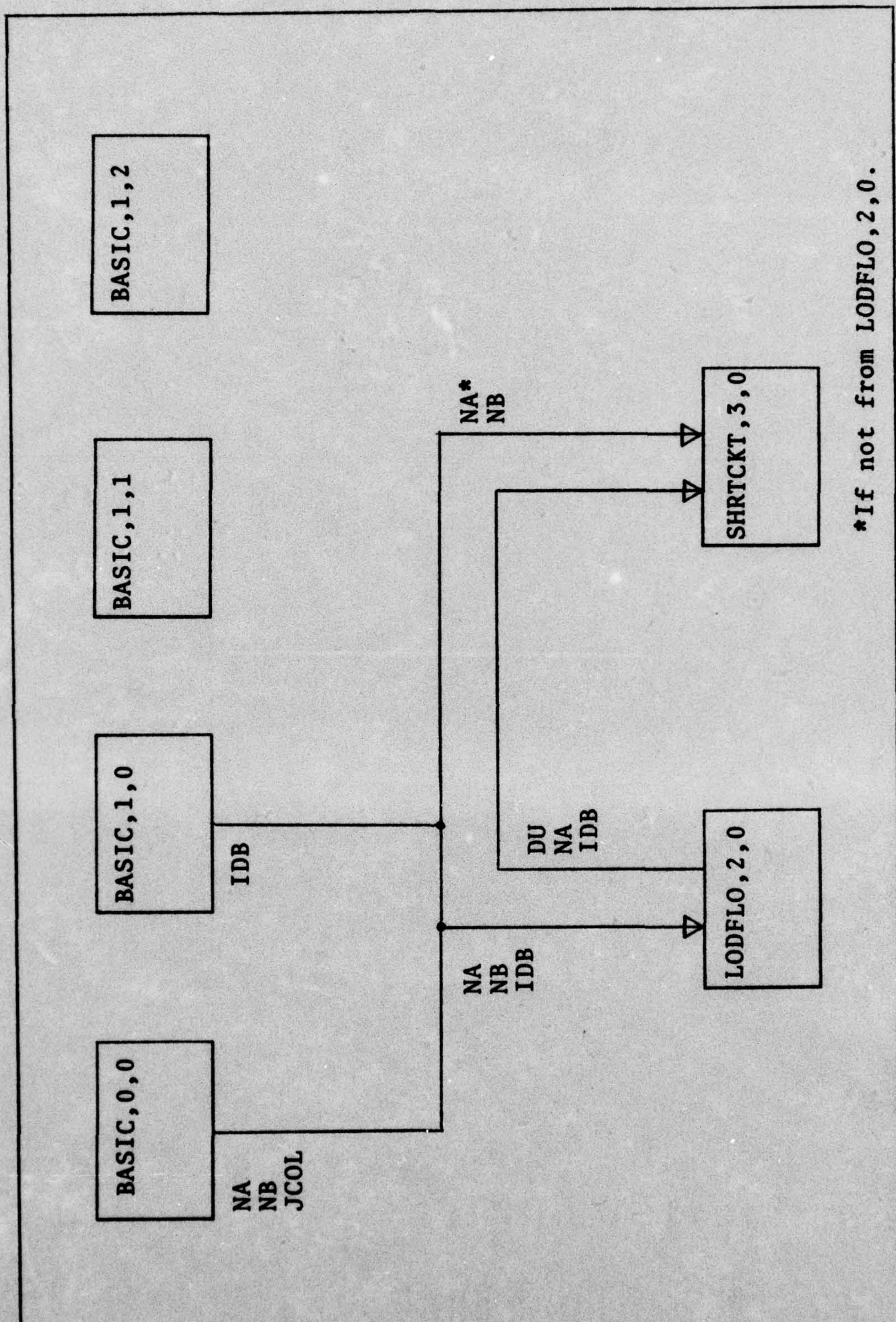


Fig. C-3. COMMON COMC Arrays and Data Flow

Table C-IV.
Common CONST Variables

Variable	Overlay Source	Definition/Use/Source
IPV	Basic,1,0	Number of Type 2 buses.
ISS	Basic,0,0 and Lodflo,2,0 (1) Shrtckt,3,0 (2)	(1) Total number of JCOL entries. (2) Number of lines in system (NL) divided by 2.
ITR1	Basic,1,0	Number of iterations for PTOL. Equal to ITRMAX1.
ITR2	Basic,1,0	Number of iterations for QTOL. Equal to ITRMAX2.
IZ	Basic,1,1 or Basic,1,2 and Shrtckt,3,0	Number of line elements to reference.
LL1	Basic,1,1 or Basic,1,2	Number of aerial and underground conductors.
LL2	Basic,1,1 or Basic,1,2	Number of fixed transformers.
LL3	Basic,1,1 or Basic,1,2	Number of autotransformers.
LL4	Basic,1,1 or Basic,1,2	Number of phase-shifter transformers.
NBUS	Basic,1,1 or Basic,1,2	Number of buses in system.
NL	Basic,1,1 or Basic,1,2 and Shrtckt,3,0	Number of lines in system times two.
NLC	Basic,1,0	Number of times loads are changed in Load Flow routine.
NOLTC	Basic,1,1 or Basic,1,2	Number of TCUL transformers.
NOTR	Basic,1,1 or Basic,1,2	Number of transformers in system.
PTOL	Basic,1,0	Tolerance for real power.
QTOL	Basic,1,0	Tolerance for reactive power in Load Flow routine.

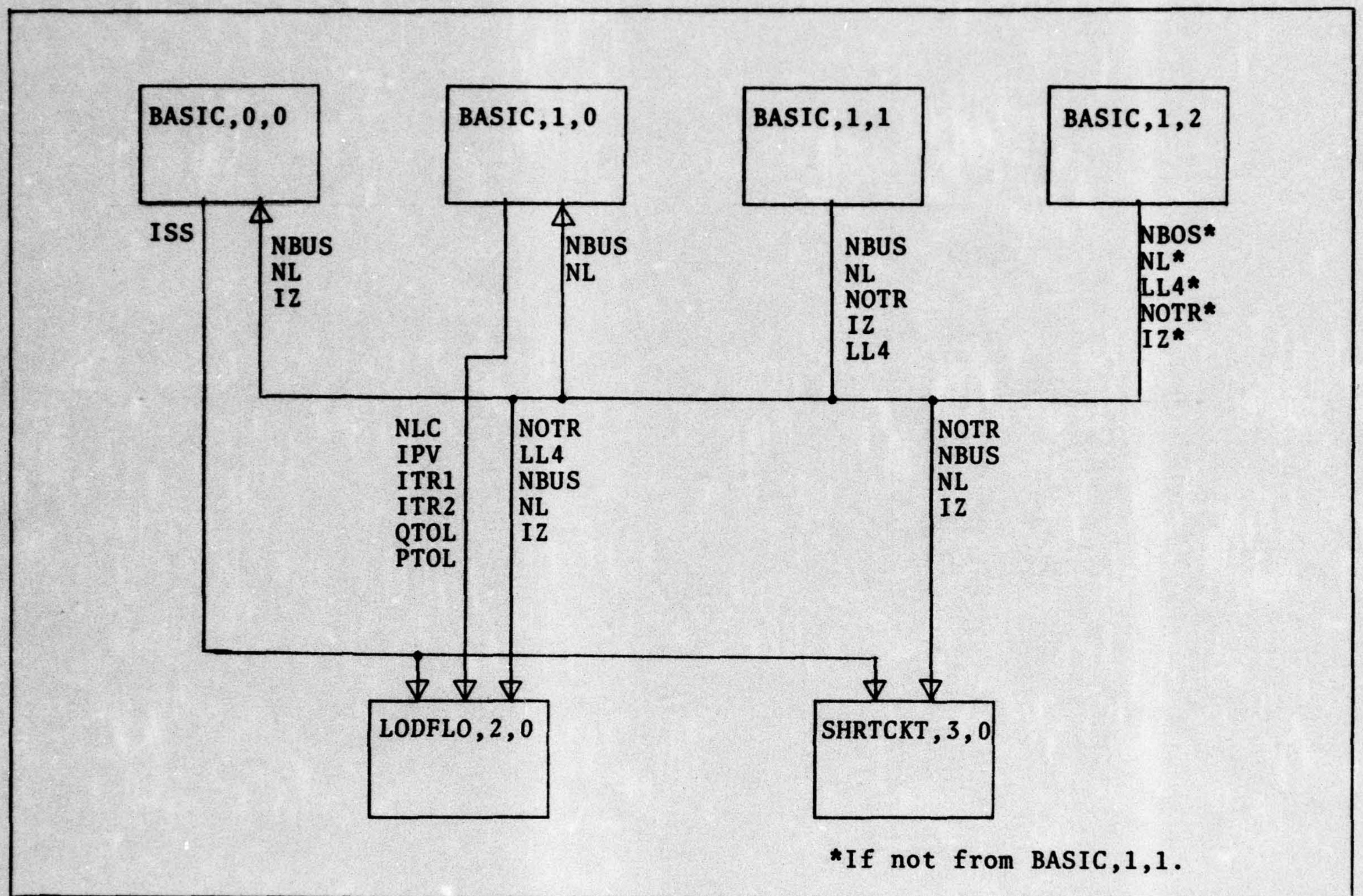


Fig. C-4. COMMON CONST Variables and Data Flow

Table C-V.

Common SAVE Variables

Variable	Overlay Source	Definition/Use/Source
IERR	Basic,0,0 or Basic,1,0 or Basic,1,1 or Basic,1,2 or Lodflo,2,0 or Shrtckt,3,0	Error counter for program.

Table C-VI.

Common ZCONST Variables

Variable	Overlay Source	Definition/Use/Source
IDUMM	Shrtckt,3,0	Second counter for number of buses in mutual impedance table.
IMUT	Shrtckt,3,0	Number of buses in mutual impedance table.
IROW	Shrtckt,3,0	Number of mutually coupled lines from subroutine MUTEST.
NBS	Shrtckt,3,0	Number of lines in a sub-system.
NOMU	Shrtckt,3,0	Number of mutually couples lines.

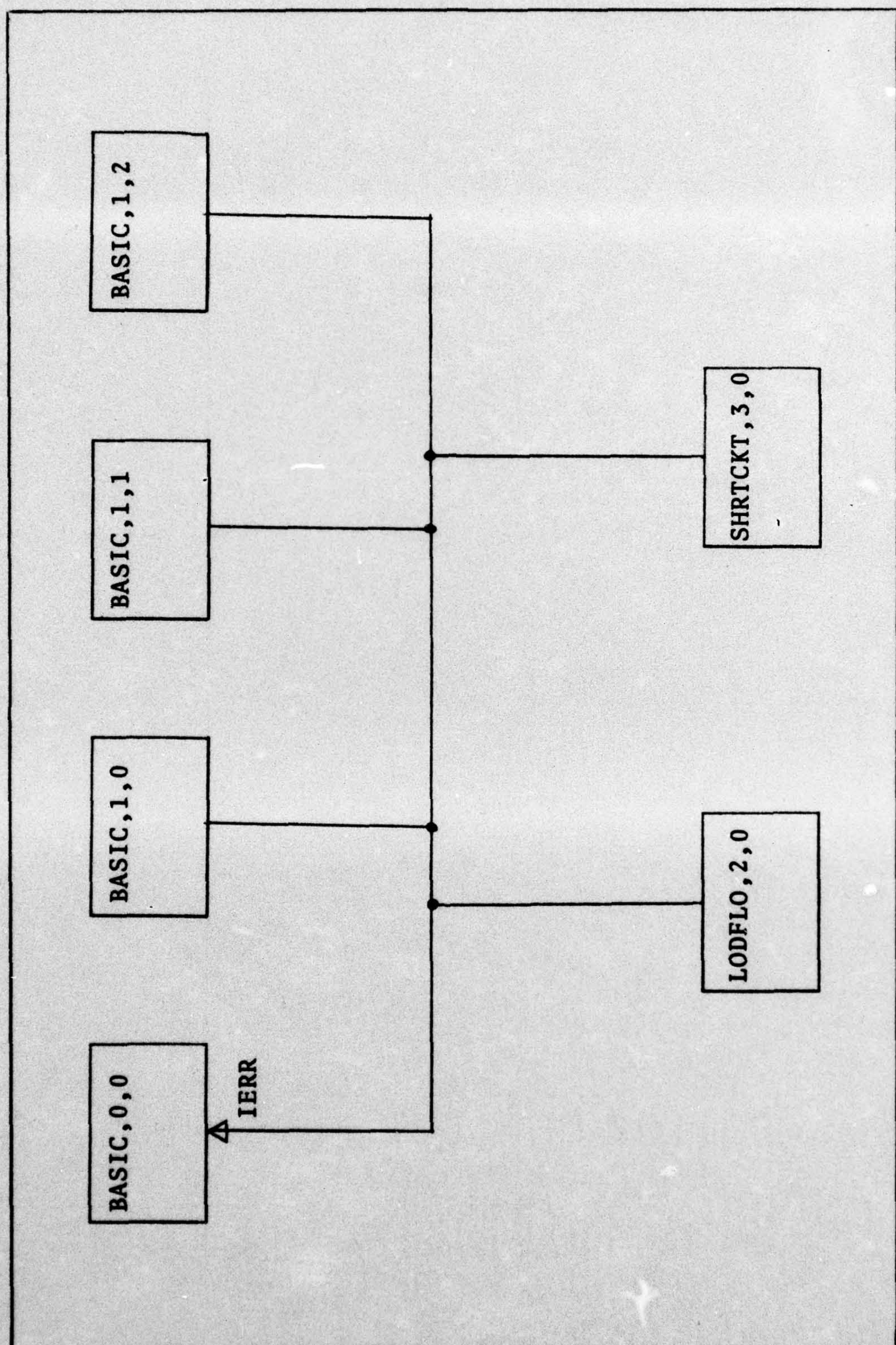


Fig. C-5. COMMON SAVE Variables and Data Flow

Table C-VII.
Common ZERO Arrays

Array(Size)	Overlay Source	Definition/Use/Comments
EBUS(250)	Shrtckt,3,0	Voltage array.
IJK(25)	Shrtckt,3,0	Bus number array of mutually coupled lines.
ISAVE(8)	Shrtckt,3,0	Bus number array in subroutine MUTEST.
ITZ(25)	Shrtckt,3,0	Additional array for mutually coupled lines.
KJI(25)	Shrtckt,3,0	Second bus number array for mutually coupled lines.
LA(25)	Shrtckt,3,0	Start bus array of mutually coupled lines.
LB(25)	Shrtckt,3,0	End bus array for mutually coupled lines.
LR(25)	Shrtckt,3,0	Array of start bus to which lines mutually coupled.
LS(25)	Shrtckt,3,0	End bus array of lines to which mutually coupled.
YCOUP(8,8)	Shrtckt,3,0	Mutual coupling matrix.
ZOBUS(2775)	Shrtckt,3,0	Zero sequence off diagonal terms of ZO matrix.
ZODIA(75)	Shrtckt,3,0	Array of diagonal zero sequence impedance terms of ZO matrix.
ZBUS(2775)	Shrtckt,3,0	Positive sequence off diagonal terms of Z matrix.
ZC(75)	Shrtckt,3,0	Impedance array used in BUS and BUSO subroutines.
ZDIA(75)	Shrtckt,3,0	Array of diagonal positive sequence terms of Z matrix.
ZM(25)	Shrtckt,3,0	Array of mutual impedance between mutually coupled lines.

Appendix D.

This appendix contains a complete listing of the PDSAP program. The numbers near the left margin are line numbers. If trying to find a particular line number in a routine, use these left margin numbers. The numbers near the right margin are sequence numbers and refer to the card numbers in the source deck. These numbers are used to insure the cards remain in proper sequence.

```
      OVERLAY(BASIC,0,0)                                                000100
      PROGRAM EXEC(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT,TAPE1,TAPE2)   000110
C  THIS PROGRAM SUPERVISES THE OVERALL EXECUTION OF THE COMPLETE PRO-   000120
C  GRAM BY MEANS OF PARAMETERS READ IN ON CONTROL CARDS.  THESE PARAM-  000130
C  ETERS ARE DEFINED AND CODED IN THE  USER'S INSTRUCTIONS.             000140
C  THE PURPOSE OF THE PROGRAM IS TO                                     000150
C  PERFORM VARIOUS STANDARD SYSTEM ANALYSIS ROUTINES ON A POWER DISTRI- 000160
C  BUTION SYSTEM.  THE PROGRAM IS SET UP TO HANDLE A 250 BUS SYSTEM WITH000170
C  500 LINES/TRANSFORMERS.  OF THE 500 LINES/TRANS.,  50 MAY BE TAP-    000180
C  CHANGING-UNDER-LOAD TYPES(TCUL'S).  THE PROGRAM WILL ALSO ACCEPT     000190
C  PHASE-ANGLE REGULATORS (MAX. OF 25).                                 000200
C  THE PROGRAM IS CAPABLE OF LOADFLOW AND SHORT-CIRCUIT ANALYSES AT THE 000210
C  PRESENT.  AN INPUT OPTION ALLOWS THE LINE DATA TO BE READ IN EITHER  000220
C  PRE-CALCULATED  OR AS "RAW" DATA, WITH THE IMPEDANCES CALCULATED BY  000230
C  THE PROGRAM. OVERALL PROGRAM REVISED NOV 76 WITH CODE NAME POSAP.    000240
      COMPLEX ZM,YCOUP,ZCOUP,ZBUS,Z0BUS,ZDIA,Z0DIA,EBUS,ZC              000250
      INTEGER CON,CHG,SCOP,OUT,CONEC,A,C,D,E                            000260
      DIMENSION TITLE(8)                                                000270
      COMMON /COMA/CON,CHG,LOOOP,SCOP,INP,OUT,F,T,BKVA,RHO1,NMAX,MAXTR, 000280
     1MAXLTC,MAXPH,ISYS,BKVA1                                           000290
      COMMON /COMB/LINA(1450),LINB(1450),G(1450),B(1450),P(250),Q(250), 000300
     1,PHB(50),PHANG(50),LTRA(250),LTRB(250),TAP(250),TMN(250),V(250),  000310
     2TMK(250),IUBPP(250),ANG(250),IBUS(250),DBP(250),UBP(3000),        000320
     3BUSNAME(250),LPHA(50),LIST(250),IUBP(250),QMIN(250),QMAX(250),    000330
     4DBPP(250),UBPP(3000),JBP(3000),JBPP(3000),ICC(250),DLP(250),      000340
     5Z0I(1450),Z0R(1450),BDIA(250),CONEC(250),DLQ(250),IPHASE(250)     000350
      COMMON/COMC/ NA(250),NB(250),JCOL(1000),DJ(1000),IDB(250)         000360
      COMMON /CONST/ NBUS,NL,ISS,IPV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC      000370
     1,ITR1,ITR2,PTOL,QTOL,NLC                                          000380
      COMMON /SAVE/IERR                                                 000390
      COMMON /ZERO/LA(25),LB(25),LR(25),LS(25),ZM(25),YCOUP(8,8),       000400
     1ZCOUP(25),IJK(25),KJI(25),ITZ(25),ISAVE(8),ZDIA(75),Z0DIA(75),    000410
     2ZBUS(2775),Z0BUS(2775),EBUS(250),ZC(75)                           000420
      COMMON /ZCONST/ NOMU,NBS,IROW,IMJT,IDUMM                          000430
 1000 FORMAT(R6,4I3)                                                    000440
 1001 FORMAT(8R10)                                                      000450
 1002 FORMAT(///1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,13X,4R10,15X,1H*/1X,   000460
     11H*,13X,4R10,15X,1H*/1X,1H*,68X,1H*/1X,70(1H*)/)                  000470
 1004 FORMAT(R6,F7.0,3F5.0)                                             000480
 1005 FORMAT(/T20,"*** PROGRAM PARAMETER CONSTANTS ***"//T6,"BASE KVA", 000490
     1T20,"FREQUENCY",T34,"TEMPERATURE",T51,"EARTH RESISTIVITY"/3X,F7.0,000500
     2" KVA",5X,F5.0," HZ",6X,F5.0," DEG. C",9X,F5.0," METER-OHM"//)    000510
 1006 FORMAT("USE OF CONTROL PARAMETERS  4 OR 6 OR 7 IS NOT ALLOWED AT T000520
     1HIS TIME.")                                                       000530
 1007 FORMAT(1X,"USE OF CON CODE",I3," NOT ALLOWED.")                   000540
 1010 FORMAT(//1X,"**** THE PROGRAM HAS TERMINATED DUE TO",I5," ERRORS!"000550
     1/T20,"LISTED ABOVE IS A DESCRIPTION OF EACH"/T20,"ERROR AND RELEVA000560
     2NT DATA FOR LOCATING"/T20,"THE ERROR SOURCE.  GOOD LUCK!")        000570
 1011 FORMAT(T3,"SB",T7,"EB",T17,"G",T31,"B",T43,"RE(Z0)",T57,"IM(Z0)"//000580
     1(2(1X,I3),3X,4(E11.5,3X))/)                                       000590
 1012 FORMAT(//1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,T23,"SORTED LINE INPUT D000600
     1ATA",T71,1H*/1X,1H*,T19,"LISTED BY ASCENDING BUS NUMBERS",T71,1H*/000610
     21X,1H*,68X,1H*/1X,70(1H*)//)                                      000620
 1017 FORMAT(/T20,"**** PROGRAM CONTROL CONSTANTS ****"//T33,"CON=",    000630
     1I3/T33,"INP=",I3/T33,"OUT=",I3/T33,"CHG=",I3//)                   000640
 1018 FORMAT(T3,"FOLLOWING IS THE SORTED LINE TABLE AS CALCULATED  "/)  000650
 1019 FORMAT(T3,"PROGRAM CONTROL CARD NOT IN PROPER FORMAT OR LOCATION. 000660
```

AD-A035 292 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCH--ETC F/G 10/2
A USER-ORIENTED POWER DISTRIBUTION SYSTEM ANALYSIS PROGRAM.(U)
DEC 76 J A UNDERWOOD
UNCLASSIFIED GE/EE/76-43 NL

3 OF 3
AD
A035292

END
DATE
FILMED
3-77

```
     1CARD WITH KEYWORD ",R6," IS REQUIRED."/)
 1020 FORMAT(//1X,70(1H*)/1X,1H*,58X,1H*/1X,1H*,9X,
     1"POWER DISTRIBUTION SYSTEM ANALYSIS PROGRAM (PDSAP)",
     29X,1H*/1X,1H*,26X,"TAPE 2 PRINTOUT",27X,1H*/1X,1H*,
     358X,1H*/1X,70(1H*)/)
 1021 FORMAT(//1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,9X,
     1"POWER DISTRIBUTION SYSTEM ANALYSIS PROGRAM (PDSAP)",
     29X,1H*/1X,1H*,26X,"TAPE 1 PRINTOUT",27X,1H*/1X,1H*,
     368X,1H*/1X,70(1H*)/)
      NMAX=1000
      MAKTR=250
      MAKLTC=50
      MAXPH=25
      IERR=LOOOP=0
      WRITE(2,1020)
      WRITE(1,1021)
      READ(5,1001) TITLE
      WRITE(2,1002) TITLE
      WRITE(1,1002) TITLE
      READ(5,1000) A,CON,INP,OUT,CHG
      C=5RPSMCON
      IF(A.NE.C) GO TO 900
      READ(5,1004) D,BKVA,F,T,RHO1
      E=5RSYSPAR
      IF(D.NE.E) GO TO 901
      IF(BKVA.EQ.0.) BKVA=100000.
      BKVA1=BKVA
      IF(F.EQ.0) F=60.
      IF(T.EQ.0) T=25.
      IF(RHO1.EQ.0) RHO1=100.
      WRITE(2,1017) CON,INP,OUT,CHG
      WRITE(1,1017) CON,INP,OUT,CHG
      WRITE(2,1005) BKVA,F,T,RHO1
      WRITE(1,1005) BKVA,F,T,RHO1
      IF(CON.EQ.0.OR.CON.GT.7) GO TO 80
      CALL OVERLAY(5HBASIC,1,0,6HRECALL)
      IF(IERR.NE.0) GO TO 950
      IF(OUT.EQ.15) GO TO 101
      GO TO(100,20,30,40,50,60,70) CON
   20 CALL OVERLAY(6HLODFLO,2,0,6HRECALL)
      IF(IERR.NE.0) GO TO 950
      GO TO 100
   30 CALL OVERLAY(7HSHRTCKT,3,0,6HRECALL)
      IF(IERR.NE.0) GO TO 950
      GO TO 100
   40 WRITE(2,1006)
      GO TO 90
   50 CALL OVERLAY(6HLODFLO,2,0,6HRECALL)
      IF(IERR.NE.0) GO TO 950
      CALL OVERLAY(7HSHRTCKT,3,0,6HRECALL)
      IF(IERR.NE.0) GO TO 950
      GO TO 100
   60 WRITE(2,1006)
      GO TO 90
   70 WRITE(2,1006)
      GO TO 90
   80 WRITE(2,1007) CON

   90 IERR=1
      GO TO 950
  100 IF(OUT.EQ.2.OR.OUT.EQ.4.OR.OUT.EQ.5.OR.OUT.EQ.10) GO TO 101
      IF(OUT.EQ.0) GO TO 101
      WRITE(1,1012)
      WRITE(1,1011) (LINA(I),LINB(I),G(I),B(I),ZOR(I),ZOI(I),I=1,NL)
  101 IF(OUT.NE.2.AND.OUT.NE.10) REWIND 1
      REWIND 2
      STOP
  900 WRITE(2,1019) C
      GO TO 949
  901 WRITE(2,1019) E
  949 IERR=1
  950 WRITE(2,1010) IERR
      WRITE(1,1010)
      WRITE(1,1011) (LINA(I),LINB(I),G(I),B(I),ZOR(I),ZOI(I),I=1,NL)
      REWIND 1
      STOP
      END
```

```
      SUBROUTINE LSORT(NL,LA,LB,LSIZE,LTAB,A,B,C,D,IE)                  001430
C     THIS SUBROUTINE SORTS TWO TABLES (LA & LB) INTO INCREASING SEQUENCE 001440
C     IN DOUBLE-PRECISION FASHION, I.E. LA IS SORTED AS THE MOST SIGNIFI- 001450
C     CANT FIGURE, AND THEN LB IF VALUES OF LA ARE EQUAL.  IN ADDITION,  001460
C     UP TO FIVE OTHER TABLES (A,B,C,D, & IE) CAN BE SORTED IN A CORRES- 001470
C     PONDING MANNER.  LTAB INDICATES HOW MANY ADDITIONAL TABLES ARE IN- 001480
C     VOLVED, WHILE LSIZE INDICATES THE NUMBER OF ENTRIES PER TABLE (FOR 001490
C     ALL TABLES).  NL INDICATES WHETHER LA & LB WILL BE SORTED IN DOUBLE- 001500
C     PRECISION FASHION (NL=2), OR SORTED IN SINGLE-PRECISION FASHION    001510
C     (NL=1) USING ONLY TABLE LA.                                        001520
      DIMENSION LA(1450),LB(1450),A(1450),B(1450),C(1450),D(1450),       001530
     1IE(1450)                                                           001540
      IF(LSIZE.LE.1) RETURN                                              001550
      M=LSIZE-1                                                          001560
      NTAB=LTAB+1                                                        001570
      DO 70 J=1,M                                                        001580
      IM=J                                                               001590
      L=J+1                                                              001600
         DO 30 I=L,LSIZE                                                 001610
         IF(LA(I)-LA(IM)) 25,10,30                                       001620
   10    IF(NL.EQ.1) GO TO 30                                            001630
         IF(LB(I).GE.LB(IM)) GO TO 30                                    001640
   25    IM=I                                                            001650
   30    CONTINUE                                                        001660
      IF(IM.LE.J) GO TO 70                                               001670
      GO TO(45,44,43,42,41,40) NTAB                                      001680
   40 ITE=IE(IM)                                                         001690
   41 TD=D(IM)                                                           001700
   42 TC=C(IM)                                                           001710
   43 TB=B(IM)                                                           001720
   44 TA=A(IM)                                                           001730
   45 LTA=LA(IM)                                                         001740
      IF(NL.EQ.1) GO TO 48                                               001750
      LTB=LB(IM)                                                         001760
   48 IF(IM.LE.J) GO TO 59                                               001770
      GO TO(55,54,53,52,51,50) NTAB                                      001780
   50 IE(IM)=IE(IM-1)                                                    001790
   51 D(IM)=D(IM-1)                                                      001800
   52 C(IM)=C(IM-1)                                                      001810
   53 B(IM)=B(IM-1)                                                      001820
   54 A(IM)=A(IM-1)                                                      001830
   55 LA(IM)=LA(IM-1)                                                    001840
      IF(NL.EQ.1) GO TO 57                                               001850
      LB(IM)=LB(IM-1)                                                    001860
   57 IM=IM-1                                                            001870
      GO TO 48                                                           001880
   59 GO TO(65,64,63,62,61,60) NTAB                                      001890
   60 IE(J)=ITE                                                          001900
   61 D(J)=TD                                                            001910
   62 C(J)=TC                                                            001920
   63 B(J)=TB                                                            001930
   64 A(J)=TA                                                            001940
   65 LA(J)=LTA                                                          001950
      IF(NL.EQ.1) GO TO 70                                               001960
      LB(J)=LTB                                                          001970
   70 CONTINUE                                                           001980
   80 RETURN                                                             001990

      END                                                                002000
```

```
      SUBROUTINE ORDER(IDO)                                             002010
C  THIS SUBROUTINE COMPUTES THE ORDER OF ELIMINATION FOR THE TRIANGULIZA002020
C  TION OF THE "A" MATRIX.  THE ORDERING SCHEME IS REFERRED TO AS THE   002030
C  DYNAMIC ORDERING SCHEME.  IT SELECTS THE NEXT ROW TO BE ELIMINATED AS002040
C  THE ONE WITH THE FEWEST TERMS IN THE REDUCED MATRIX.                 002050
      INTEGER OUT                                                       002060
      DIMENSION IDUM(50)                                                002070
      COMMON /COMA/CON,CHG,LODOP,SCOP,INP,OUT,F,T,BKVA,RHO1,NMAX,MAXTR, 002080
     1MAXLTC,MAXPH,ISYS,BKVA1                                           002090
      COMMON /COMB/LINA(1450),LINB(1450),G(1450),B(1450),P(250),Q(250), 002100
     1LPHB(50),PHANG(50),LTRA(250),LTRB(250),TAP(250),TMN(250),V(250),  002110
     2TMX(250),IUBPP(250),ANG(250),IBUS(250),DBP(250),UBP(3000),        002120
     3BUSNAME(250),LPHA(50),LIST(250),IUBP(250),QMIN(250),QMAX(250),    002130
     4DBPP(250),UBPP(3000),JBP(3000),JBPP(3000),ICC(250),DLP(250),      002140
     5ZOI(1450),ZOR(1450),BDIA(250),CONEC(250),DLQ(250),IPHASE(250)     002150
      COMMON/COMC/ NA(250),NB(250),JCOL(1000),DJ(1000),IDB(250)         002160
      COMMON /CONST/ NBUS,NL,ISS,IPV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC      002170
     1,ITR1,ITR2,PTOL,QTOL,NLC                                          002180
C  THE FOLLOWING LOOP FORMS THE JCOL AND NA VECTORS FROM THE            002190
C  LINE DATA READ IN BY THE INPUT PROGRAM.  THE JCOL VECTOR CONTAINS A  002200
C  LIST OF ALL THE J TERMS FROM EACH ROW OF THE BUS ADMITTANCE MATRIX.  002210
C  THE NA VECTOR IS A LIST OF THE TOTAL NO. OF CONNECTIONS TO EACH BUS. 002220
      DO 5 I=1,250                                                      002230
    5 NA(I)=0                                                           002240
      J=M=1                                                             002250
      DO 10 I=1,NL                                                      002260
      IF(LINA(I).EQ.0.OR.LINB(I).EQ.0) GO TO 10                         002270
      JCOL(M)=LINB(I)                                                   002280
      M=M+1                                                             002290
    7 IF(LINA(I).NE.J) GO TO 8                                          002300
      NA(J)=NA(J)+1                                                     002310
      GO TO 10                                                          002320
    8 J=J+1                                                             002330
      GO TO 7                                                           002340
   10 CONTINUE                                                          002350
      ISS=NL-2*IZ                                                       002360
C  IN THE FOLLOWING LOOP, THE BUS LIST IS SCANNED AND THE NUMBER        002370
C  OF CONNECTIONS TO EACH IS COMPARED.  THE BUS WITH THE FEWEST CON-    002380
C  NECTIONS IS SELECTED AS THE NEXT BUS TO BE ELIMINATED IN THE TRI-    002390
C  ANGULATION ROUTINE.  THE ACTUAL ELIMINATION IS SIMULATED ON THE JCOL 002400
C  VECTOR, WITH "J" TERMS ADDED OR DELETED AS APPROPRIATE.  THE NUMBER  002410
C  OF CONNECTIONS TO THE BUS IS ALTERED ACCORDINGLY.  THE LOOP THEN     002420
C  REPEATS, AND THE REMAINING BUSSES SCANNED TO FIND THE BUS WITH THE   002430
C  FEWEST CONNECTIONS IN THE REDUCED MATRIX, UNTIL ALL BUSSES HAVE BEEN 002440
C  REORDERED.                                                           002450
      NB(1)=0                                                           002460
      DO 100 I=1,NBUS                                                   002470
      ICON=25                                                           002480
      IZZ=I-1                                                           002490
          DO 12 L=1,NBUS                                                002500
          IF(NA(L).GE.ICON) GO TO 12                                    002510
              DO 11 LL=1,IZZ                                            002520
              IF(L.EQ.NB(LL)) GO TO 12                                  002530
   11          CONTINUE                                                 002540
          ICON=NA(L)                                                    002550
          NB(I)=IRW=L                                                   002560
   12      CONTINUE                                                     002570
```

```
      KKK=0
C  THIS LOOP SCANS JCOL TO FIND ROWS WITH ELEMENTS IN THE I'TH COLUMN
C  AND THEN STORES THE BUS ROW NUMBER IF IT HAS NOT BEEN PREVIOUSLY
C  OPERATED UPON.
          DO 20 M=1,ISS
          IF(JCOL(M).NE.IRW) GO TO 20
               DO 15 L=1,I
               IF(IRN(M).EQ.NB(L)) GO TO 20
   15          CONTINUE
          KKK=KKK+1
          IDUM(KKK)=IRN(M)
   20     CONTINUE
C  THE FOLLOWING LOOP PERFORMS THE SIMULATED ROW ELIMINATION ON ALL
C  ROWS BELOW THE I'TH ROW.  SUBROUTINE ADDRDEL IS CALLED TO ADD OR
C  DELETE AN ELEMENT FROM THE JCOL VECTOR IF NECCESSARY.
      IF(KKK.EQ.0) GO TO 100
          DO 50 N=1,KKK
          IJJ=0
   25     KI=JADD(IRW)
          KF=KI+NA(IRW)-1
               DO 40 J=KI,KF
               IF(JCOL(J).EQ.IRW) GO TO 40
               K1=JADD(IDUM(N))
               K2=K1+NA(IDUM(N))-1
               IF(IJJ.EQ.1) GO TO 32
                    DO 30 L=K1,K2
                    IF(JCOL(L).EQ.IRW) GO TO 35
   30               CONTINUE
   32                IF(IRN(K1).EQ.JCOL(J)) GO TO 40
                    DO 31 L=K1,K2
                    IF(JCOL(L).EQ.JCOL(J)) GO TO 40
   31               CONTINUE
               CALL ADDRDEL(L-1,1,J)
                NA(IDUM(N))=NA(IDUM(N))+1
               GO TO 40
   35          CALL ADDRDEL(L,-1,0)
                NA(IDUM(N))=NA(IDUM(N))-1
               IJJ=1
               GO TO 25
   40          CONTINUE
   50     CONTINUE
  100 CONTINUE
      IF(OUT.EQ.2.OR.OUT.EQ.7.OR.OUT.EQ.8.OR.OUT.EQ.10) GO TO 101
      WRITE(1,1000)
      WRITE(1,1001) (NB(I),I=1,NBUS)
 1000 FORMAT(///1X,70(1H*)/1X,1H*,58X,1H*/1X,1H*,T16,"REORDERED BUSLIST
     1RETURNED BY SUBROUTINE ORDER",T71,1H*/1X,1H*,68X,1H*/1X,70(1H*)//)
 1001 FORMAT(3X,13I5)
  101 RETURN
      END
```

```
      SUBROUTINE ADDRDEL(L,IC,J)
C     THIS SUBROUTINE ADDS OR DELETES AN ENTRY IN THE JCOL TABLE.  IC IS A
C     PARAMETER WHICH DETERMINES IF AN ENTRY IS ADDED OR DELETED.  IC=1 RE-
C     SULTS IN AN ADDED ENTRY, AND IC=-1 RESULTS IN A DELETION.  OTHER
C     TABLE ENTRIES ARE MOVED TO ALLOW FOR THE ADDED OR DELETED ENTRY.  THE
C     PARAMATER ISS (TOTAL NUMBER OF TABLE ENTRIES) IS INCREMENTED OR DE
C     REMENTED AS APPROPRIATE. THE L PARAMETER DETERMINES THE POSITION OF
C     THE ADDED OR DELETED ENTRY, AND J IS THE PARAMETER THAT DETERMINES
C     THE VALUE OF THE ADDED TERM (NOT USED FOR DELETIONS).
      COMMON/COMC/ NA(250),NB(250),JCOL(1000),DJ(1000),IOB(250)
      COMMON /CONST/ NBUS,NL,ISS,IPV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC
     1,ITR1,ITR2,PTOL,QTOL,NLC
      IF(IC.EQ.1) GO TO 20
      LS=ISS-1
      DO 10 I=L,LS
      JCOL(I)=JCOL(I+1)
   10 CONTINUE
      JCOL(ISS)=0
      ISS=ISS-1
      RETURN
   20 LS=ISS-L-2
      JC=JCOL(J)
      JCOL(ISS+1)=JCOL(ISS)
      JCOL(ISS)=JCOL(ISS-1)
      DO 30 I=1,LS
      JCOL(ISS-I)=JCOL(ISS-I-1)
   30 CONTINUE
      JCOL(L+1)=JC
      ISS=ISS+1
      RETURN
      END

      FUNCTION IRN(M)
C     THIS FUNCTION CALCULATES THE ROW NUMBER OF AN  ENTRY IN THE LINE
C     TABLE FROM THE GIVEN POSITION, L.
      COMMON/COMC/ NA(250),NB(250),JCOL(1000),DJ(1000),IOB(250)
      COMMON /CONST/ NBUS,NL,ISS,IPV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC
     1,ITR1,ITR2,PTOL,QTOL,NLC
      ISUM=0
      DO 10 II=1,NBUS
      ISUM=ISUM+NA(II)
      IF(ISUM.GE.M) GO TO 11
   10 CONTINUE
      II=II-1
   11 IRN=II
      RETURN
      END

      FUNCTION JADD(I)
C     THIS FUNCTION CALCULATES THE POSITION OF THE FIRST ENTRY OF A GIVEN
C     ROW IN THE LINE TABLE, GIVEN THE ROW NUMBER.
      COMMON/COMC/ NA(250),NB(250),JCOL(1000),DJ(1000),IOB(250)
      ISUM=0
      IF(I.EQ.1) GO TO 11
      MJI=I-1
      DO 10 J=1,MJI
   10 ISUM=ISUM+NA(J)
      JADD=ISUM+1
      RETURN
   11 JADD=1
      RETURN
      END
```

```
      SUBROUTINE PERUNIT(Z,Z0,PH,VP,S)                                  003680
      INTEGER PH                                                        003690
      COMPLEX Z,Z0                                                      003700
      COMMON /COMA/CON,CHG,LODOP,SCOP,INP,OUT,F,T,BKVA,RHO1,NMAX,MAXTR, 003710
     1MAKLTC,MAXPH,IYS,BKVA1                                            003720
C  FIRST PART IS TO CONVERT IMPED. VALUES IN PERCENT FROM               003730
C  BASE KVA OF S TO PERUNIT ON BKVA.                                    003740
      IF(S.EQ.0.) GO TO 10                                              003750
      Z=(Z*BKVA)/(S*100.)                                               003760
      Z0=Z0*BKVA/(S*100.)                                               003770
      RETURN                                                            003780
C  THIS SECTION CONVERTS VALUE IN OHMS TO PERUNIT ON BKVA.              003790
   10 IF(PH.EQ.1) BKVA=BKVA/3.                                          003800
      ZB=(1000.*VP*VP)/BKVA                                             003810
      Z=Z/ZB                                                            003820
      Z0=Z0/ZB                                                          003830
      IF(PH.EQ.1) BKVA=BKVA1                                            003840
      RETURN                                                            003850
      END                                                               003860
      OVERLAY (BASIC,1,0)                                               003870
      PROGRAM INPUT                                                     003880
C  THIS PROGRAM READS IN THE BASE CASE LINE DATA.  TWO OPTIONS ARE PRO- 003890
C  VIDED FOR INPUT:  1) LINE DATA INPUT AS IMPEDANCES  PER UNIT LENGTH  003900
C  (WIRE/CABLE) OR PER CENT IMPEDANCE (TRANSFORMERS), WITH THE CONVER-  003910
C  SION TO PER UNIT ACCOMPLISHED BY THE COMPUTER; OR 2) LINE DATA INPUT 003920
C  AS "RAW" DATA, I.E. WIRE SIZE, WIRE TYPE, LENGTH OF RUN, TRANSFORMER 003930
C  SIZE, TRANSFORMER CONNECTION, LINE-LINE VOLTAGE, AND NUMBER OF PHASES003940
C  IN THE CIRCUIT.  THIS IS THE MINIMUM DATA REQUIRED FOR THE PROGRAM TO003950
C  RUN UNDER OPTION 2.  IF OTHER INFORMATION, SUCH AS STRANDING, EQUIV. 003960
C  SPACING, OR TRANSFORMER IMPEDANCES (PER CENT) ARE AVAILABLE, THESE   003970
C  MAY BE INPUT AS WELL UNDER OPTION 2, WITH RESULTING IMPROVED ACCURACY003980
C  OF THE RESULTS.                                                      003990
      INTEGER CON,CHG,SCOP,OUT                                          004000
      COMMON /COMA/CON,CHG,LODOP,SCOP,INP,OUT,F,T,BKVA,RHO1,NMAX,MAXTR, 004010
     1MAKLTC,MAXPH,ISYS,BKVA1                                           004020
      COMMON /SAVE/IERR                                                 004030
      COMMON/CONST/ NBUS,NL,ISS,IPV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC       004040
     1,ITR1,ITR2,PTOL,QTOL,NLC                                          004050
 1000 FORMAT(1X,"ERROR IN INPUT PARAMETER  INP  CODE.  PLEASE REFER TO P004060
     1ROGRAM INSTRUCTIONS."/)                                           004070
      IF(INP.GT.1.OR.INP.LT.0) GO TO 100                                004080
      IF(INP.EQ.0) CALL OVERLAY(5HBASIC,1,1,6HRECALL)                   004090
      IF(INP.EQ.1) CALL OVERLAY(5HBASIC,1,2,6HRECALL)                   004100
      IF(CON.EQ.1.OR.CON.EQ.3) RETURN                                   004110
      IF(CON.EQ.4.AND.(SCOP.EQ.0.OR.SCOP.EQ.2)) RETURN                  004120
      IF(OUT.EQ.15) RETURN                                              004130
      IF(IERR.NE.0) RETURN                                              004140
      CALL BUSIN(DUM)                                                   004150
      IF(IERR.NE.0) RETURN                                              004160
      CALL ORDER(0)                                                     004170
      RETURN                                                            004180
  100 WRITE(1,1000)                                                     004190
      RETURN                                                            004200
      END                                                               004210
```

```
      SUBROUTINE BUSIN(DUM)                                             004220
      INTEGER CON,CHG,SCOP,OUT,CONEC,A,C                                004230
      COMMON /COMA/CON,CHG,LODOP,SCOP,INP,OUT,F,T,BKVA,RHO1,NMAX,MAXTR, 004240
     1MAXLTC,MAXPH,ISYS,BKVA1                                           004250
      COMMON /COMB/LINA(1450),LINB(1450),G(1450),B(1450),P(250),Q(250), 004260
     1_P49(50),PHANG(50),LTRA(250),LTRB(250),TAP(250),TMN(250),V(250),  004270
     2TMX(250),IUBPP(250),ANG(250),IBUS(250),DBP(250),UBP(3000),        004280
     3BUSNAME(250),LPHA(50),LIST(250),IUBP(250),QMIN(250),QMAX(250),    004290
     4DBPP(250),UBPP(3000),JBP(3000),JBPP(3000),ICC(250),DLP(250),      004300
     5ZOI(1450),ZOR(1450),BDIA(250),CONEC(250),DLQ(250),IPHASE(250)     004310
      COMMON/COMC/ NA(250),NB(250),JCOL(1000),DJ(1000),IDB(250)         004320
      COMMON /CONST/ NBUS,NL,ISS,IPV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC      004330
     1,ITR1,ITR2,PTOL,QTOL,NLC                                          004340
      COMMON /SAVE/ IERR                                                004350
 1000 FORMAT(I2,I3,A10,2F5.0,4F10.0)                                    004360
 1001 FORMAT(1X,"TOO MANY SLACK BUSSES - ADDITIONAL ONE DECLARED IS ",  004370
     1A10/1X," BUS NO. ",I3," BUS DATA CARD NO. ",I3/)                  004380
 1002 FORMAT(1X,"TOO MANY PV BUSSES - LAST ONE DECLARED IS ",A10,       004390
     1" BUS NO. ",I3," BUS DATA CARD NO. ",I3/)                         004400
 1003 FORMAT(///1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,16X,"SUMMARIZED INPUT B004410
     1US DATA: PER-UNIT",T71,1H*/1X,1H*,T21,"LISTED BY ASCENDING BUS NUM004420
     2BERS",T71,1H*/1X,1H*,68X,1H*/1X,70(1H*)//)                        004430
 1004 FORMAT(T38,"POWER"/T3,"NO.",T7,"TYPE",T12,"V(MAG)",T20,           004440
     1"V(ANG-DEG)",T34,"REAL",T42,"REACTIVE",T54,"Q(MIN)",T64,          004450
     2"Q(MAX)"//(1X,I3,3X,I1,3X,F5.3,3X,F8.4,2X,F9.5,1X,F9.5,2X,F8.4,   004460
     32X,F8.4))                                                         004470
 1005 FORMAT(R6,I4,I4,2F7.5,I3)                                         004480
 1006 FORMAT(T3,"PROGRAM CONTROL CARD NOT IN PROPER FORMAT OR LOCATION. 004490
     1CARD WITH KEYWORD ",R6," IS REQUIRED."/)                          004500
 1014 FORMAT(1X,"BUS",I3," SHOULD BE CONNECTED TO A LINE BUS OF THESAME.004510
     1CHECK INPUT LINE LIST FOR THIS BUS NUMBER."/)                     004520
 1015 FORMAT(1X,"BUS LIST SHOULD HAVE BUS",I3,". CHECK BUS INPUT DATA FO004530
     1R POSSIBLE MISSING OR EXTRA BUS CARD."/)                          004540
      IXX=IPV=0                                                         004550
      READ(5,1005) A,ITR1,ITR2,PTOL,QTOL,NLC                            004560
      C=$RLOFLOW                                                        004570
      IF(A.NE.C) GO TO 903                                              004580
      DO 20 I=1,NBUS                                                    004590
      READ(5,1000)IDB(I),IBUS(I),BUSNAME(I),V(I),ANG(I),P(I),Q(I),QMN,  004600
     1QMX                                                               004610
      IF(IDB(I).EQ.3.AND.IXX.NE.0) GO TO 100                            004620
      IF(IDB(I).EQ.3.AND.IXX.EQ.0) IXX=1                                004630
      IF(IDB(I).EQ.2) IPV=IPV+1                                         004640
      IF(IPV.GT.50) GO TO 101                                           004650
      IF(V(I).EQ.0) V(I)=1.0                                            004660
      P(I)=P(I)/BKVA                                                    004670
      Q(I)=Q(I)/BKVA                                                    004680
      QMIN(I)=QMN/BKVA                                                  004690
      QMAX(I)=QMX/BKVA                                                  004700
      LIST(I)=IBUS(I)                                                   004710
      ANG(I)=.01745329*ANG(I)                                           004720
      GO TO 20                                                          004730
  100 WRITE(1,1001) BUSNAME(I),IBUS(I),I                                004740
      IERR=IERR+1                                                       004750
      GO TO 20                                                          004760
  101 WRITE(1,1002) BUSNAME(I),IBUS(I),I                                004770
      IERR=IERR+1                                                       004780
```

```
   20  CONTINUE
       IF(IERR.NE.0) RETURN
       CALL LSORT(1,IBUS,0,NBUS,5,V,ANG,P,Q,IDB)
       CALL LSORT(1,LIST,0,NBUS,3,BUSNAME,QMIN,QMAX,0,0)
C  LOOPS 201 AND 202 CHECK THAT EACH LINE BUS HAS LOAD BUS.
       DO 201 II=1,NBUS
       DO 202 JJ=1,NL
       IF(LINA(JJ).EQ.IBUS(II)) GO TO 201
  202 CONTINUE
       GO TO 901
  201 CONTINUE
C  LOOPS 204 AND 205 CHECK THAT EACH LOAD BUS HAS A LINE BUS.
       DO 204 IA=1,NL
       IF(LINA(IA).EQ.0) GO TO 204
       DO 205 JB=1,NBUS
       IF(LINA(IA).EQ.IBUS(JB)) GO TO 204
  205 CONTINUE
       GO TO 902
  204 CONTINUE
       IF(OUT.EQ.2.OR.OUT.EQ.8.OR.OUT.EQ.10) RETURN
       WRITE(1,1003)
       DO 208 I=1,NBUS
       ANG(I)=ANG(I)*57.29578
  208 CONTINUE
       WRITE(1,1004) (IBUS(I),IDB(I),V(I),ANG(I),P(I),Q(I),QMIN(I),
     1QMAX(I),I=1,NBUS)
       DO 209 I=1,NBUS
       ANG(I)=ANG(I)*.01745329
  209 CONTINUE
       GO TO 950
  901 WRITE(2,1014) IBUS(II)
       GO TO 940
  902 WRITE(2,1015) LINA(IA)
       GO TO 940
  903 WRITE(2,1006) C
  940 IERR=IERR+1
       WRITE(1,1004) (IBUS(I),IDB(I),V(I),ANG(I),P(I),Q(I),QMIN(I),
     1QMAX(I),I=1,NBUS)
       WRITE(2,*) "ANGLE VALUES IN RADIANS"
  950 RETURN
       END
```

```
      OVERLAY (BASIC,1,1)                                               005200
      PROGRAM LINDATA                                                   005210
      COMPLEX Z,Z0,ZN,Y,Z0G,Z0AG                                        005220
      REAL NN,L,L1,L2                                                   005230
      INTEGER PH,C,SB,EB,STR,CON,CHG,SCOP,OUT,CH,CONEC,TC,ID            005240
      COMMON /COMA/CON,CHG,LOOOP,SCOP,INP,OUT,F,T,BKVA,RHO1,NMAX,MAXTR, 005250
     1MAXLTC,MAXPH,ISYS,BKVA1                                           005260
      COMMON /COMB/LINA(1450),LINB(1450),G(1450),B(1450),P(250),Q(250), 005270
     1.PHB(50),PHANG(50),LTRA(250),LTRB(250),TAP(250),TMN(250),V(250),  005280
     2TMX(250),IUBPP(250),ANG(250),IBUS(250),DBP(250),UBP(3000),        005290
     3BUSNAME(250),LPHA(50),LIST(250),IUBP(250),QMIN(250),QMAX(250),    005300
     4JBPP(250),UBPP(3000),JBP(3000),JBPP(3000),ICC(250),DLP(250),      005310
     5Z0I(1450),Z0R(1450),BDIA(250),CONEC(250),DLQ(250),IPHASE(250)     005320
      COMMON/COMC/ NA(250),NB(250),JCOL(1000),DJ(1000),IDB(250)         005330
      COMMON /CONST/ NBUS,NL,ISS,IPV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC      005340
     1,ITR1,ITR2,PTOL,QTOL,NLC                                          005350
      COMMON /SAVE/IERR                                                 005360
  200 FORMAT(2I3,F5.0,I2,F6.0,I2,I1,F7.0,I2,F4.0,F6.0,5F5.0,I1,2F6.0,I1)005370
 1000 FORMAT(1X,"ERROR IN WIRE SIZE INPUT:  LINE DATA CARD NUMBER ",I5, 005380
     1" PLEASE REFER TO PROGRAM INSTRUCTIONS."/)                        005390
 1001 FORMAT(1X,"INVALID TRANSFORMER SIZE/VOLTAGE RATING:  LINE DATA CAR005400
     1D NUMBER ",I5,"  PLEASE REFER TO PROGRAM INSTRUCTIONS."/)         005410
 1002 FORMAT(1X,"INVALID TRANSFORMER VOLTAGE INPUT:  LINE DATA CARD NUMB005420
     1ER",I5,"  PLEASE REFER TO PROGRAM INSTRUCTIONS."/)                005430
 1003 FORMAT(1X,"ERROR HAS RESULTED IN POSITIVE AND ZERO SEQUENCE IMPEDA005440
     1NCES= ZERO.  CHECK DATA ENTRIES ON CARD NUMBER",I5/)              005450
 1004 FORMAT(1X,"NUMBER OF LTC'S INPUT EXCEEDS MAXLTC= ",I5,      "LINE 005460
     1DATA CARD NUMBER ",I5/)                                           005470
 1005 FORMAT(1X,"NUMBER OF LINES INPUT HAS EXCEEDED NMAX=",I5,".  LINE I005480
     1NPUT DATA CARD NUMBER=",I5/)                                      005490
 1006 FORMAT(1X,"NUMBER OF PHASE-SHIFTERS HAS EXCEEDED MAXPH=",I5,".  LI005500
     1NE INPUT DATA CARD NUMBER=",I5/)                                  005510
 1007 FORMAT(1X,"NUMBER OF TRANSFORMERS HAS EXCEEDED MAXTR=",I5,".  LINE005520
     1 DATA CARD NUMBER=",I5/)                                          005530
 1008 FORMAT(1X,"PROGRAM ERROR: STATEMENT NO. 500: SHOULDN'T REACH THIS 005540
     1POINT IF ID IS LESS THAN 5.  DEBUG!!"/)                           005550
 1010 FORMAT(1X,"ERROR ON INPUT LINE CARD ",I3," WITH SB ",I3," AND EB "005560
     1,I3,". CHECK CARD FORMAT AND VALUES."/)                           005570
 1011 FORMAT(1X,"ERROR WITH ID OR C VALUE.  LINE CARD",I3," WITH SB= ", 005580
     1I3," AND EB= ",I3," ."/)                                          005590
 1019 FORMAT(///1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,T29,"LINDATA SUBROUTINE005600
     1",T71,1H*/1X,1H*,T20,"ASSEMBLED INPUT LINE DATA  (OHMS)",T71,1H*/ 005610
     21X,1H*,68X,1H*/1X,70(1H*)//)                                      005620
 1020 FORMAT(///1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,T29,"LINDATA SUBROUTINE005630
     1",T71,1H*/1X,1H*,T19,"ASSEMBLED INPUT LINE DATA  (PER-UNIT)",T71, 005640
     21H*/1X,1H*,68X,1H*/1X,70(1H*)//)                                  005650
 1021 FORMAT(5X,"CONDUCTOR NO. ",I3/5X,"FROM - TO",5X,"RE(Z)",8X,"IM(Z)"005660
     1,8X,"RE(Z0)",7X,"IM(Z0)"/6X,I3,2X,I3,3X,4(F10.4,3X)/)             005670
 1022 FORMAT(5X,"TRANSFORMER, FIXED NO. ",I3/5X,"FROM - TO",5X,"RE(Z)", 005680
     19X,"IM(Z)",8X,"RE(Z0)",7X,"IM(Z0)"/5X,I3,2X,I3,3X,                005690
     24(F10.4,3X)/3X,"TAP",5X,"CONEC CODE"/2X,F7.5,5X,I3/)              005700
 1023 FORMAT(5X,"TRANSFORMER, AUTO. NO. ",I3/5X,"FROM - TO",5X,"RE(Z)", 005710
     19X,"IM(Z)",8X,"RE(Z0)",7X,"IM(Z0)"/5X,I3,2X,I3,3X,                005720
     24(F10.4,3X)/3X,"TAP",5X,"CONEC CODE"/2X,F5.3,6X,I3/)              005730
 1024 FORMAT(5X,"TRANSFORMER, LTC NO. ",I3/5X,"FROM - TO",5X,"RE(Z)",   005740
     19X,"IM(Z)",8X,"RE(Z0)",7X,"IM(Z0)"/5X,I3,2X,I3,3X,4(F10.4,3X)/5X, 005750
     2"TAP",7X,"TMN",7X,"TMX",5X,"CONEC CODE"/3X,3(F7.5,3X),3X,I3/)     005760
```

```
 1025 FORMAT(5X,"TRANSFORMER, PHASE-SHIFTER NO. ",I3/5X,"FROM - TO",5X, 005770
     1"RE(Z)",8X,"IM(Z)",8X,"RE(Z0)",7X,"IM(Z0)"/6X,I3,2X,I3,3X,4(F10.4,005780
     23X)/5X,"TAP",7X,"PHANG",5X,"ZONED CODE"/3X,F7.5,3X,F9.4,6X,I3/)   005790
 1026 FORMAT(5X,"SERIES CAPACITOR NO. ",I3/5X,"FROM - TO",5X,            005800
     1"RE(Z)",8X,"IM(Z)",8X,"RE(Z0)",7X,"IM(Z0)"/6X,I3,2X,I3,3X,         005810
     24(F10.4,3X)/)                                                     005820
 1027 FORMAT(5X,"SERIES REACTOR NO. ",I3/5X,"FROM - TO",5X,"RE(Z)",      005830
     13X,"IM(Z)",8X,"RE(Z0)",7X,"IM(Z0)"/5X,I3,2X,I3,3X,4(F10.4,3X)/)   005940
 1028 FORMAT(3X,"OUT CODE 15. PRINT OF LINDATA CARDS FOLLOWS."/          005850
     11X,"SB EB  VP ID  L   C PH  S  STR DM   SG  STRG DMCG DMGG REZN IM005860
     2ZN NG REZ  IMZ CH"/32X,"PHI  VS  TMNN TMXX  TPI",11X,"TC"/)       005870
      N=NL=NOPH=NOLTC=NOTR=LL1=LL2=LL3=LL4=0                            005880
      IF(OUT.EQ.1) GO TO 202                                            005890
      IF(OUT.EQ.2.OR.OUT.EQ.3.OR.OUT.EQ.5.OR.OUT.EQ.8) GO TO 209        005900
      IF(OUT.EQ.10) GO TO 209                                           005910
      WRITE(1,1020)                                                     005920
      GO TO 209                                                         005930
  202 WRITE(1,1019)                                                     005940
  209 IF(OUT.EQ.15) WRITE(2,1029)                                       005950
  210 READ(5,200) SB,EB,VP,ID,L,C,PH,S,STR,DM,VS,TMNN,TMXX,TPI,ZN,TC,Z, 005960
     1CH                                                                005970
      IF(EB.EQ.0) GO TO 930                                             005980
      IF(OUT.EQ.15) GO TO 921                                           005990
      IF(S.EQ.0) S=BKVA                                                 006000
      ZBE=VP*VP*1000/S                                                  006010
      N=N+1                                                             006020
      IF(VP.EQ.0.OR.ID.EQ.0.OR.PH.EQ.0) GO TO 859                       006030
      NL=NL+2                                                           006040
      IF(NL.GT.NMAX) GO TO 855                                          006050
      IF(ID.LT.5) LL1=LL1+1                                             006060
      IF(ID.EQ.0) GO TO 860                                             006070
      IF(ID.GT.11) GO TO 850                                            006080
      GO TO(211,212,300,400,500,500,500,500,820,830) ID                 006090
C  THE FOLLOWING CALCULATES RHO FOR COPPER AERIAL, AND SETS CONSTANT F2 006100
  211 F2=.0636                                                          006110
      RHO=10.86*((241.+T)/266.)                                         006120
      GO TO 214                                                         006130
C  THE FOLLOWING CALCULATES RHO FOR ACSR AERIAL, AND SETS CONSTANT F2:  006140
  212 F2=.036                                                           006150
      RHO=17.34*((228.+T)/253.)                                         006160
C  THE FOLLOWING SECTION CALCULATES THE DC RESISTENCE (OHMS/MILE),      006170
C  AND THE AC RESISTANCE (OHMS/MILE) BASED ON THE INPUT TEMP. AND       006180
C  AND FREQUENCY.                                                       006190
  214 DCRES=(RHO/(.98*S))*5280.                                         006200
      RMR=F2*SQRT(F/DCRES)                                              006210
      BER=(2304.*(64.-RMR**4)+RMR**8)/147456.                           006220
      BEI=(576.*RMR**2-RMR**6)/2304.                                    006230
      BERP=(-1152.*RMR**3+RMR**7)/18432.                                006240
      BEIP=(192.*RMR-RMR**5)/384.                                       006250
      ACRES=(DCRES*RMR/2.)*((BER*BEIP-BEI*BERP)/(BEIP*BEIP+BERP*BERP))  006260
C  THE FOLLOWING SECTION DETERMINES THE F1 FACTOR USED TO CALCULATE     006270
C  GMR OF THE CONDUCTOR.  IF STRANDING INFO. IS NOT INPUT WITH THE      006280
C  DATA, AN AVERAGE VALUE OF F1 IS ASSIGNED BASED ON CONDUCTOR SIZE.    006290
C  TWO DIFFERENT ROUTINES ARE USED: ONE IS FOR COPPER, AND THE OTHER    006300
C  IS FOR ACSR.                                                         006310
      IF(STR.EQ.0.AND.ID.EQ.1) GO TO 220                                006320
      IF(STR.EQ.0.AND.ID.EQ.2) GO TO 221                                006330
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      IF(ID.EQ.2) GO TO 216
      IF(STR.EQ.37) F1=.983
      IF(STR.EQ.19) F1=.869
      IF(STR.EQ.12) F1=.913
      IF(STR.EQ.7) F1=.822
      IF(STR.EQ.3) F1=.842
      IF(STR.EQ.1) F1=.775
      GO TO 217
  216 IF(STR.EQ.54) F1=.99
      IF(STR.EQ.30) F1=1.056
      IF(STR.EQ.26) F1=1.008
      IF(STR.EQ.6) GO TO 222
      GO TO 217
  220 IF(S.GT.500000) F1=.883
      IF(S.EQ.500000) F1=.875
      IF(S.EQ.450000.OR.S.EQ.400000) F1=.869
      IF(S.LE.350000.AND.S.GT.211600) F1=.891
      IF(S.EQ.211600) F1=.865
      IF(S.EQ.167800) F1=.8675
      IF(S.EQ.133100.OR.S.EQ.105500) F1=.922
      IF(S.EQ.83690) F1=.932
      IF(S.EQ.66370.OR.S.EQ.52630) F1=.814
      IF(S.LT.52630.AND.S.GT.20820) F1=.91
      IF(S.LT.26250) F1=.778
      GO TO 217
  221 IF(S.GE.266800) F1=.99
  222 IF(S.LT.266800.AND.S.GT.41590) F1=.3757
      IF(S.EQ.41690) F1=.514
      IF(S.EQ.33120) F1=.549
      IF(S.EQ.26230) F1=.584
C  THIS SECTION CALCULATES GMR (DS), AND THEN THE INDUCTIVE REACTANCE
C  OUT TO ONE FOOT RADIUS (XA, OHMS/MILE).  THE CONDUCTOR SPACING
C  FACTOR (DM) IS THEN DETERMINED.  IF A VALUE FOR DM IS NOT INPUT,
C  A DEFAULT VALUE IS ASSIGNED BASED ON THE LINE VOLTAGE.  THE IN-
C  DUCTIVE REAC. DUE TO COND. SPACING (XD) IS THEN CALCULATED AND
C  ADDED TO XA AS THE TOTAL AC IND. REACTANCE.  THE POS. SEQ. IM-
C  PEDANCE (Z) IS FORMED, AND MULTIPLIED BY THE CONDUCTOR LENGTH IN
C  MILES.
  217 DS=F1*SQRT((S*7.854E-7)/3.1415926)/12.
      IF(DS.EQ.0) GO TO 859
      XA=4.657E-3*F*ALOG10(1./DS)
      IF(M.EQ.1) 240,218
  218 IF(DM.EQ.0..AND.VP.LE.25) DM=4.69
      IF(DM.EQ.0..AND.VP.GT.25) DM=12.37
      XD=4.657E-3*F*ALOG10(DM)
      ACINDR=XA+XD
      Z=CMPLX(ACRES,ACINDR)*L/5280.
C  THE FOLLOWING SECTION CALCULATES THE ZERO SEQ. IMPEDANCE:
      RE=4.764E-3*F
      XE=6.985E-3*F*ALOG10(4665600.*RHO1/F)
      Z01=ACRES+RE
      Z02=XA+XE-2.*XD
      Z0=CMPLX(Z01,Z02)*L/5280.
      IF(TC.EQ.0) 900,230
C  THIS SECTION ADJUSTS ZERO SEQ IMPEDANCE FOR GROUND WIRES.
C  VARIABLES LISTED IN INSTRUCTIONS ARE EQUATED AS FOLLOWS:
C  STRG=TMNN; NG=TC; DMCG=TMXX; DMSG=TPI; SG=VS.  ROUTINE USES
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C  SECTION 214-217 TO CALCULATE XA AND ACRES FOR GND WIRES.
  230 M=1
      IF(VS.EQ.0) GO TO 232
      S=VS
      IF(TMNN.EQ.0) GO TO 235
      STR=TMNN
      GO TO 214
  232 IF(ID.EQ.1) GO TO 234
      S=133100.
      GO TO 235
  234 S=105500.
  235 STR=0
      GO TO 214
  240 IF(TMXX.NE.0) GO TO 241
      TMXX=4.
  241 XD2=4.657E-3*F*ALOG10(TMXX)
      IF(TPI.NE.0) GO TO 242
      TPI=15.
  242 IF(TC.LT.2) TPI=1.
      XD3=4.657E-3*F*ALOG10(TPI)
      Z03=ACRES*3/TC+RE
      Z04=3*XA/TC-3*XD3/TC+XE
      Z0G=CMPLX(Z03,Z04)
      IF(Z0G.EQ.0) GO TO 859
      Z05=RE
      Z06=XE-3*XD2
      Z0AG=CMPLX(Z05,Z06)
      Z0=Z0-Z0AG*Z0AG*L/(5280.*Z0G)
      M=0
      TMXX=TC=TMNN=TPI=VS=0
      GO TO 900
C  THE FOLLOWING SECTION PROCESSES ALUMINUM UG CABLE.
  300 L1=L/1000.
      IF(PH.EQ.3) GO TO 320
      IF(S.GT.133100) GO TO 302
      IF(S.EQ.133100) GO TO 303
      IF(S.GT.66370) GO TO 304
      IF(S.EQ.66370) 305,306
  302 IF(S.EQ.167800) GO TO 307
      IF(S.GT.250000) GO TO 308
      IF(S.EQ.250000) 309,310
  303 Z=CMPLX(.1645,.0515)*L1
      Z0=CMPLX(.4977,.1722)*L1
      GO TO 900
  304 IF(S.EQ.105500) 311,312
  305 Z=CMPLX(.328,.0509)*L1
      Z0=CMPLX(.7116,.4256)*L1
      GO TO 900
  306 IF(S.NE.41740) GO TO 315
      Z=CMPLX(.5225,.0562)*L1
      Z0=CMPLX(.8495,.5811)*L1
      GO TO 900
  307 Z=CMPLX(.1285,.049)*L1
      Z0=CMPLX(.426,.1205)*L1
      GO TO 900
  308 IF(S.EQ.350000) 313,314
  309 Z=CMPLX(.087,.044)*L1
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      Z0=CMPLX(.3032,.0474)*L1
      GO TO 900
  310 IF(S.NE.211600) GO TO 850
      Z=CMPLX(.1025,.0463)*L1
      Z0=CMPLX(.359,.0782)*L1
      GO TO 900
  311 Z=CMPLX(.205,.0543)*L1
      Z0=CMPLX(.577,.2604)*L1
      GO TO 900
  312 IF(S.NE.83690) GO TO 850
      Z=CMPLX(.2615,.0569)*L1
      Z0=CMPLX(.6471,.3333)*L1
      GO TO 900
  313 Z=CMPLX(.063,.0402)*L1
      Z0=CMPLX(.2212,.0175)*L1
      GO TO 900
  314 IF(S.NE.300000) GO TO 850
      Z=CMPLX(.073,.0419)*L1
      Z0=CMPLX(.2584,.0306)*L1
      GO TO 900
  315 IF(S.EQ.16510) GO TO 318
      Z=CMPLX(.827,.0711)*L1
      Z0=CMPLX(1.08,.79)*L1
      GO TO 900
  318 IF(S.NE.16510) GO TO 850
      Z=CMPLX(1.315,.0782)*L1
      Z0=CMPLX(1.18,1.07)*L1
      GO TO 900
  320 IF(S.EQ.250000) GO TO 321
      IF(S.GT.250000) GO TO 322
      IF(S.GT.133100) GO TO 323
      IF(S.EQ.133100) 324,325
  321 Z=CMPLX(.1034,.0929)*L1
      Z0=CMPLX(.3084,.1124)*L1
      GO TO 900
  322 IF(S.GT.500000) GO TO 326
      IF(S.EQ.500000) 327,328
  323 IF(S.EQ.211600) 329,330
  324 Z=CMPLX(.178,.0926)*L1
      Z0=CMPLX(.4692,.2474)*L1
      GO TO 900
  325 IF(S.NE.105500) GO TO 333
      Z=CMPLX(.218,.0956)*L1
      Z0=CMPLX(.521,.2916)*L1
      GO TO 900
  326 IF(S.EQ.1000000) 331,332
  327 Z=CMPLX(.0664,.0579)*L1
      Z0=CMPLX(.1653,.0436)*L1
      GO TO 900
  328 IF(S.NE.350000) GO TO 339
      Z=CMPLX(.0832,.0763)*L1
      Z0=CMPLX(.2314,.07)*L1
      GO TO 900
  329 Z=CMPLX(.1178,.0859)*L1
      Z0=CMPLX(.3495,.1412)*L1
      GO TO 900
  330 IF(S.NE.167000) GO TO 850
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      Z=CMPLX(.143,.0894)*L1
      Z0=CMPLX(.4046,.1836)*L1
      GO TO 900
  331 Z=CMPLX(.049,.05)*L1
      Z0=CMPLX(.0905,.0241)*L1
      GO TO 900
  332 IF(S.NE.750000) GO TO 850
      Z=CMPLX(.0548,.0583)*L1
      Z0=CMPLX(.1188,.0312)*L1
      GO TO 900
  333 IF(S.EQ.41740) GO TO 334
      IF(S.GT.41740) 335,336
  334 Z=CMPLX(.535,.105)*L1
      Z0=CMPLX(.989,.424)*L1
      GO TO 900
  335 IF(S.EQ.66370) GO TO 337
      IF(S.NE.83690) GO TO 850
      Z=CMPLX(.276,.097)*L1
      Z0=CMPLX(.635,.330)*L1
      GO TO 900
  336 IF(S.EQ.16510) GO TO 338
      IF(S.NE.26250) GO TO 850
      Z=CMPLX(.847,.111)*L1
      Z0=CMPLX(1.48,.466)*L1
      GO TO 900
  337 Z=CMPLX(.344,.1)*L1
      Z0=CMPLX(.705,.37)*L1
      GO TO 900
  338 Z=CMPLX(1.335,.118)*L1
      Z0=CMPLX(2.27,.51)*L1
      GO TO 900
  339 IF(S.NE.300000) GO TO 850
      Z=CMPLX(.093,.0797)*L1
      Z0=CMPLX(.2698,.0922)*L1
      GO TO 900
C  THE FOLLOWING SECTION PROCESSES COPPER UG CABLE:
  400 L2=L/1000.
      IF(PH.EQ.3) GO TO 420
      IF(S.GT.105500) GO TO 402
      IF(S.EQ.105500) GO TO 403
      IF(S-66370) 404,405,405
  402 IF(S-167800) 407,408,409
  403 Z=CMPLX(.123,.0543)*L2
      Z0=CMPLX (.4218,.1188)*L2
      GO TO 900
  404 IF( S.NE.41740) GO TO 410
      Z=CMPLX(.318,.0662)*L2
      Z0=CMPLX (.7044,.4279)*L2
      GO TO 900
  405 Z=CMPLX(.2,.0609)*L2
      Z0=CMPLX (.5749,.2392)*L2
      GO TO 900
  406 IF ( S.NE.83690) GO TO 850
      Z=CMPLX (.159,.0569)*L2
      Z0=CMPLX (.4939,.1706)*L2
      GO TO 900
  407 IF ( S.NE.133100) GO TO 850
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      Z=CMPLX (.099,.0515)*L2
      Z0=CMPLX (.3563,.0757)*L2
      GO TO 900
  408 Z=CMPLX (.079,.049)*L2
      Z0=CMPLX (.2958,.0446)*L2
      GO TO 900
  409 IF ( S.NE.211600) GO TO 412
      Z=CMPLX (.0625,.0453)*L2
      Z0=CMPLX (.2386,.0212)*L2
      GO TO 900
  410 IF(S.EQ.26250) GO TO 411
      IF(S.NE.16510) GO TO 850
      Z=CMPLX(.799,.0792)*L2
      Z0=CMPLX(1.01,.735)*L2
      GO TO 900
  411 Z=CMPLX(.501,.0711)*L2
      Z0=CMPLX(.802,.555)*L2
      GO TO 900
  412 IF(S-300000) 413,414,415
  413 IF(S.NE.250000) GO TO 950
      Z=CMPLX(.0527,.0444)*L2
      Z0=CMPLX(.2003,.0133)*L2
      GO TO 900
  414 Z=CMPLX(.044,.0418)*L2
      Z0=CMPLX(.1716,.0094)*L2
      GO TO 900
  415 IF(S.NE.350000) GO TO 950
      Z=CMPLX(.071,.0736)*L2
      Z0=CMPLX(.1751,.0511)*L2
      GO TO 900
  420 IF ( S.GT.250000) GO TO 421
      IF ( S.EQ.250000) GO TO 422
      IF ( S.GT.133100) GO TO 423
      IF ( S.EQ.133100) 424,425
  421 IF ( S.GT.500000) GO TO 426
      IF ( S.EQ.500000) 427,428
  422 Z=CMPLX(.078,.0774)*L2
      Z0=CMPLX(.2008,.0598)*L2
      GO TO 900
  423 IF ( S.EQ.211600) 429,430
  424 Z=CMPLX(.1177,.031)*L2
      Z0=CMPLX(.349,.144)*L2
      GO TO 900
  425 IF ( S.NE.105500) GO TO 433
      Z=CMPLX(.1448,.0345)*L2
      Z0=CMPLX(.4063,.1854)*L2
      GO TO 900
  426 IF ( S.EQ.1000000) 431,432
  427 Z=CMPLX (.055,.038)*L2
      Z0=CMPLX(.106,.0295)*L2
      GO TO 900
  428 IF ( S.NE.350000) GO TO 440
      Z=CMPLX (.0652,.069)*L2
      Z0=CMPLX(.1494,.0416)*L2
      GO TO 900
  429 Z=CMPLX(.0849,.0515)*L2
      Z0=CMPLX(.2317,.0728)*L2
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      GO TO 900
  430 IF ( S.NE.167800) GO TO 850
      Z=CMPLX (.0984,.0858)*L2
      Z0=CMPLX(.2906,.1044)*L2
      GO TO 900
  431 Z=CMPLX(.0402,.0364)*L2
      Z0=CMPLX(.0554,.0137)*L2
      GO TO 900
  432 IF (S.NE.750000) GO TO 850
      Z=CMPLX(.046,.0452)*L2
      Z0=CMPLX(.0724,.0222)*L2
      GO TO 900
  433 IF(S-41740) 436,434,435
  434 Z=CMPLX(.33,.106)*L2
      Z0=CMPLX(.924,.244)*L2
      GO TO 900
  435 IF(S.EQ.66370) GO TO 437
      IF(S.NE.83690) GO TO 850
      Z=CMPLX(.17,.097)*L2
      Z0=CMPLX(.476,.203)*L2
      GO TO 900
  436 IF(S.EQ.16510) GO TO 438
      IF(S.NE.26250) GO TO 850
      Z=CMPLX(.52,.111)*L2
      Z0=CMPLX(1.456,.266)*L2
      GO TO 900
  437 Z=CMPLX(.220,.1)*L2
      Z0=CMPLX(.616,.22)*L2
      GO TO 900
  438 Z=CMPLX(.81,.110)*L2
      Z0=CMPLX(1.9,.295)*L2
      GO TO 900
  440 IF(S.NE.300000) GO TO 850
      Z=CMPLX(.071,.0736)*L2
      Z0=CMPLX(.1751,.0511)*L2
      GO TO 900
C  ALL TRANSFORMER PROCESSING ENTERS AT THIS STATEMENT TO UPDATE THE
C  NOTR COUNTER.  A CHECK IS MADE TO DETERMINE IF THE MAXIMUM NO. OF
C  TRANSFORMERS HAS BEEN EXCEEDED:  IF NOT, A BRANCH IS MADE TO THE
C  APPROPRIATE STATEMENT NO. TO COMPLETE PROCESSING OF THE PARTICULAR
C  TYPE OF TRANSFORMER. IMPED, WHEN TC=0,IS PERCENT.
C  TXFR IMPED. CAN BE IN OHMS,PERUNIT,OR NOT SPECIFIED. TC VARIABLE
C  CONTROLS. 0=NOT SPECFIED,1=IN OHMS,2=IN PERUNIT.  ZBE IS BASE
C  IMPED. OF TXFR.  PERUNIT IS CONVERTED TO OHMS WHEN TC=2.
  500 NOTR=NOTR+1
      IF(NOTR.GT.MAXTR) GO TO 857
C  FOLLOWING 3 STATEMENTS BLOCK C CODES 6 TO 10 FOR FIXED,TCUL,
C  AND AUTO TXFRS. CODES 6 TO 10 ARE FOR 3 WINDING TXFRS.
      IF(C.GT.5.AND.ID.EQ.6) GO TO 850
      IF(C.GT.5.AND.ID.EQ.7) GO TO 850
      IF(C.GT.5.AND.ID.EQ.5) GO TO 860
      GO TO (858,858,858,858,518,500,700,800,858,859) ID
C  THE FOLLOWING SECTION PROCESSES FIXED TRANSFORMERS
  518 LL2=LL2+1
      IF(VP.GT.230) GO TO 852
      IF(TPI.EQ.0) TPI=1.0
      IADD=40
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      IF(TS.EQ.1) GO TO 501
      IF(TS.EQ.0) GO TO 519
      Z=ZBF*Z
      GO TO 501
  519 IF (PH.EQ.3) S=S/3.
      IF (S.GT.500) GO TO 520
      IF (S.GE.100) GO TO 501
      IF (S.GE.50) GO TO 502
      IF (S.GE.25) GO TO 503
      IF (S.GE.10) GO TO 504
      IF (S.GE.1) GO TO 505
      GO TO 851
  501 IF (VP.GT.2.5) GO TO 506
      Z1=.00375*(S-100)+3.3
      K=.004*(S-100)+3.1
      GO TO 500
  502 IF (VP.GT.2.5) GO TO 507
      Z1=.018*(S-50)+2.4
      K=.02*(S-50)+2.1
      GO TO 500
  503 IF (VP.GT.2.5) GO TO 508
      Z1=-.004*(S-25)+2.5
      K=.004*(S-25)+2.0
      GO TO 500
  504 IF (VP.GT.2.5) GO TO 509
      Z1=.02*(S-10)+2.2
      K=.0333*(S-10)+1.5
      GO TO 500
  505 IF (VP.GT.2.5) GO TO 510
      Z1=2.2
      K=.0444*(S-1)+1.1
      GO TO 500
  506 IF(VP.GT.15) GO TO 511
      Z1=.0045*(S-100)+3.2
      K=.005*(S-100)+2.9
      GO TO 500
  507 IF(VP.GT.15) GO TO 512
      Z1=.014*(S-50)+2.5
      K=.016*(S-50)+2.1
      GO TO 500
  508 IF(VP.GT.15) GO TO 513
      Z1=.008*(S-25)+2.3
      K=.016*(S-25)+1.7
      GO TO 500
  509 IF(VP.GT.15) GO TO 514
      Z1=-.0067*(S-10)+2.4
      K=.0267*(S-10)+1.3
      GO TO 500
  510 IF(VP.GT.15) GO TO 851
      Z1=-.0444*(S-1)+2.0
      K=.0556*(S-1)+.8
      GO TO 500
  511 IF(VP.GT.25) GO TO 515
      Z1=5.2
      K=.00025*(S-100)+5.0
      GO TO 500
  512 IF(VP.GT.25) GO TO 516
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      Z1=5.2
      X=.002*(S-50)+4.9
      GO TO 580
  513 IF(VP.GT.25) GO TO 651
      Z1=5.2
      X=.004*(S-25)+4.8
      GO TO 580
  514 IF(VP.GT.25) GO TO 651
      Z1=5.2
      X=.0257*(S-10)+4.4
      GO TO 580
  515 Z1=6.5
      X=.00025*(S-100)+6.3
      GO TO 580
  516 Z1=5.5
      X=5.3
      GO TO 580
  520 IF(PH.EQ.3) S=3.*S
      IF(C.GT.5) GO TO 550
      IF(VP.GT.34.5) GO TO 521
      X=SQRT(VP)+2.2*(1./ALOG10(VP))
      GO TO 579
  521 X=SQRT(VP)+2.*(1./ALOG(VP))
      GO TO 579
  550 X=2.*SQRT(VP)+6.4*(1./ALOG10(VP))
  579 Z=CMPLX(0.,X)
      IF(ID.EQ.6) GO TO 550
      IF(ID.EQ.7) GO TO 710
      IF(ID.EQ.8) GO TO 901
      GO TO 581
  580 IF(PH.EQ.3) S=3.0*S
      R=SQRT(Z1*Z1-X*X)
      Z=CMPLX(R,X)
      IF(ID.EQ.6) GO TO 550
      IF(ID.EQ.7) GO TO 710
      IF(C.GT.5) Z=1.732*Z
  581 Z0=Z+3.0*ZN
      GO TO 901
C  THE FOLLOWING SECTION PROCESSES AUTOTRANSFORMERS:
  600 IF(TPI.EQ.0) TPI=1.0
      LL3=LL3+1
      IADD=60
      IF(PH.EQ.1) BKVA=BKVA/3.
      ZB=(1000.*VP*VP)/BKVA
      IF(PH.EQ.1) BKVA=BKVA1
      IF(TC.EQ.1) GO TO 649
      IF(TC.EQ.0) GO TO 319
      Z=ZBE*Z
  649 GO TO(662,661,664,661,667,664,665,666) C
  650 GO TO(652,651,654,651,657,654,655,656) C
  651 Z=.4167*Z
  661 Z0=Z+300.*ZN/ZB
      GO TO 901
  652 Z=.4167*Z
  662 Z0=CMPLX(0.,0.)
      GO TO 901
  654 Z=.4167*Z
```

```
  664 Z0=Z+48.*ZN/Z8                                          010900
      GO TO 901                                               010910
  655 Z=.4167*Z                                               010920
  665 Z0=1.87*Z                                               010930
      GO TO 901                                               010940
  656 Z=.229*Z                                                010950
  666 Z0=Z+180.*ZN/ZB                                         010960
      GO TO 901                                               010970
  657 Z=.4167*Z                                               010980
  667 Z0=3.36*Z+48.*ZN/ZB                                     010990
      GO  TO 901                                              011000
C  THE FOLLOWING SECTION PROCESSES LOAD TAP-CHANGERS:         011010
  700 NOLTC=NOLTC+1                                           011020
      IF(NOLTC.GT.MAXLTC) GO TO 854                           011030
      IF(TPI.EQ.0) TPI=1.0                                    011040
      IADD=70                                                 011050
      NN=VP/VS                                                011060
      IF(TMNN.EQ.0) TMNN=.9                                   011070
      IF(TMXX.EQ.0) TMXX=1.1                                  011080
      IF(TC.EQ.1) GO TO 710                                   011090
      IF(TC.EQ.0) GO TO 519                                   011100
      Z=ZBE*Z                                                 011110
  710 IF(PH.EQ.1) BKVA=BKVA/3.                                011120
      ZB=(1000.*VP*VP)/BKVA                                   011130
      Z0=Z+300.*ZN/(NN*ZB)                                    011140
      IF(PH.EQ.1) BKVA=BKVA1                                  011150
      GO TO 901                                               011160
C  THE FOLLOWING SECTION PROCESSES PHASE-SHIFTERS:            011170
  800 NOPH=NOPH+2                                             011180
      LL4=NOPH/2                                              011190
      IF(LL4.GT.MAXPH) GO TO 856                              011200
      IF(TPI.EQ.0) TPI=1.0                                    011210
      IADD=90                                                 011220
      IF(TC.EQ.0) GO TO 550                                   011230
      IF(TC.EQ.1) GO TO 901                                   011240
      Z=Z*ZBE                                                 011250
  801 IF(PH.EQ.1) BKVA=BKVA/3                                 011260
      ZB=(1000.*VP*VP)/BKVA                                   011270
      IF(PH.EQ.1) BKVA=BKVA1                                  011280
      Y=300.*ZN/ZB                                            011290
      GO TO (802,802,802,803,803,803,804,805) C               011300
  802 IF(C.EQ.1) Z0=2.23*Z                                    011310
      IF(C.EQ.2) Z0=Z*(3.+.6*Y)                               011320
      IF(C.EQ.3) Z0=1.4*Z+.24*Y                               011330
      Z=1.4*Z                                                 011340
      GO TO 901                                               011350
  803 IF(C.EQ.4) Z0=Z                                         011360
      IF(C.EQ.5) Z0=1.2*Z+.27*Y                               011370
      IF(C.EQ.6) Z0=.8*Z+.27*Y                                011380
      Z=1.4*Z                                                 011390
      GO TO 901                                               011400
  804 Z0=2.23*Z                                               011410
      Z=.9*Z                                                  011420
      GO TO 901                                               011430
  805 Z0=3.9*Z                                                011440
      Z=.8*Z                                                  011450
      GO TO 901                                               011460
```

```
C  THE FOLLOWING SECTION PROCESSES SERIES CAPACITORS:
  820 NOCAP=NOCAP+1
      IF(TC.EQ.0) GO TO 822
      IF(TC.EQ.2) Z=Z*ZBE
      Z0=Z
      GO TO 901
  822 Z1=VP*VP/S
      Z=CMPLX(0.,-Z1)
      XE=5.985E-3*F*ALOG10(4665600.*RHO1/F)
      Z01=Z1+XE
      Z0=CMPLX(0.,-Z01)
      GO TO 901
C  THE FOLLOWING SECTION PROCESSES SERIES REACTORS:
  830 NOREAC=NOREAC+1
      IF(TC.EQ.0) GO TO 832
      IF(TC.EQ.2) Z=Z*ZBE
      Z0=Z
      GO TO 901
  832 Z1=VP*VP/S
      Z=CMPLX(0.,Z1)
      XE=5.985E-3*F*ALOG10(4665600.*RHO1/F)
      Z01=Z1+XE
      Z0=CMPLX(0.,Z01)
      GO TO 901
  850 WRITE(2,1000) N
      GO TO 840
  851 WRITE(2,1001) N
      GO TO 840
  852 WRITE(2,1002) N
      GO TO 840
  853 WRITE(2,1003) N
  840 IERR=IERR+1
      GO TO 210
  854 WRITE(2,1004) MAXLTC,N
      IERR=IERR+1
      RETURN
  855 WRITE(2,1005) NMAX,N
      IERR=IERR+1
      RETURN
  856 WRITE(2,1006) MAXPH,N
      IERR=IERR+1
      RETURN
  857 WRITE(2,1007) MAXTR,N
      IERR=IERR+1
      RETURN
  858 WRITE(2,1008)
      IERR=IERR+1
      GO TO 210
  859 WRITE(2,1010) N,S9,E9
      IERR=IERR+1
      RETURN
  860 WRITE(2,1011) N,S8,E8
      IERR=IERR+1
      RETURN
  900 S=0.
      IF(ID.LT.3) GO TO 901
      F1=F/60.
```

```
      Z1=F1*AIMAG(Z)
      Z2=F1*AIMAG(Z0)
      F2=F-60.
      Z3=F2+REAL(Z)
      Z4=F2+REAL(Z0)
      Z=CMPLX(Z3,Z1)
      Z0=CMPLX(Z4,Z2)
  901 Z1=CABS(Z)
      Z2=CABS(Z0)
      IF(TC.GE.1) S=0.
      IF(Z1.EQ.0.AND.Z2.EQ.0) GO TO 853
      CALL PERUNIT(Z,Z0,PH,VP,S)
      IF(OUT.EQ.10) GO TO 909
      IF(OUT.EQ.2.OR.OUT.EQ.3.OR.OUT.EQ.5.OR.OUT.EQ.8) GO TO 909
      IF(OUT.EQ.1) Z=Z*VP*VP*1000/BKVA
      IF(OUT.EQ.1) Z0=Z0*VP*VP*1000/BKVA
      S=0.
      GO TO(902,902,902,902,903,904,905,906,907,908) ID
  902 WRITE(1,1021) LL1,SB,EB,Z,Z0
      GO TO 909
  903 WRITE(1,1022) LL2,SB,EB,Z,Z0,TPI,C
      GO TO 909
  904 WRITE(1,1023) LL3,SB,EB,Z,Z0,TPI,C
      GO TO 909
  905 WRITE(1,1024) NOLTC,SB,EB,Z,Z0,TPI,TMNN,TMXX,C
      GO TO 909
  906 WRITE(1,1025) LL4,SB,EB,Z ,Z0,TPI,DM,C
  907 WRITE(1,1026) NOCAP,SB,EB,Z,Z0
      GO TO 909
  908 WRITE(1,1027) NOREAC,SB,EB,Z,Z0
  909 IF(OUT.EQ.1) CALL PERUNIT(Z,Z0,PH,VP,S)
      IF(IPHASE(SB).NE.3.AND.SB.NE.0) IPHASE(SB)=PH
      IF(IPHASE(EB).NE.3) IPHASE(EB)=PH
      LINA(NL)=EB
      LINB(NL)=SB
      LINA(NL-1)=SB
      LINB(NL-1)=EB
C   PHI=DM,THIS SECTION FOR PHASE-SHIFTER TRANS.
      IF(DM.EQ.0) GO TO 910
      LPHA(NOPH)=EB
      LPHB(NOPH)=SB
      LPHA(NOPH-1)=SB
      LPHB(NOPH-1)=EB
      PHANG(NOPH-1)=DM*.01745329
      PHANG(NOPH)=-PHANG(NOPH-1)
  910 IF(ID.LT.5) GO TO 920
      LTRA(NOTR)=SB
      LTRB(NOTR)=EB
      TAP(NOTR)=TPI
      TMN(NOTR)=TMNN
      TMX(NOTR)=TMXX
      ICS(NOTR)=C+IADD
  920 Y=1./Z
      G(NL)=REAL(Y)
      B(NL)=AIMAG(Y)
      Z0R(NL)=REAL(Z0)
      Z0I(NL)=AIMAG(Z0)
```

```
      G(NL-1)=G(NL)
      B(NL-1)=B(NL)
      ZOR(NL-1)=ZOR(NL)
      ZOI(NL-1)=ZOI(NL)
  921 IF(OUT.NE.15) GO TO 929
      WRITE(2,200) SB,EB,VP,ID,L,C,P4,S,STR,DM,VS,TMNN,TMXX,TPI,ZN,TD,Z,
     1CM
  929 CONTINUE
      GO TO 210
  930 IF(IERR.NE.0) RETURN
      IF(OUT.EQ.15) RETURN
      CALL LSORT(2,LINA,LINB,NL,4,G,B,ZOR,ZOI,0)
      CALL LSORT(2,LTRA,LTRB,NOTR,5,TAP,TMN,TMX,0,ISC)
      CALL LSORT(2,LP4A,LP4B,NOP4,1,P4ANG,0,0,0,0)
      DO 945 I=1,250
  945 CONEC(I)=0
      IZ=0
      J=1
      DO 950 I=1,NL
      IF(LINA(I).EQ.0) GO TO 947
  948 IF(LINA(I).NE.J) GO TO 949
      CONEC(J)=CONEC(J)+1
      GO TO 950
  949 J=J+1
      GO TO 948
  947 IZ=IZ+1
  950 CONTINUE
      NBUS=J
      RETURN
      END
```

```
      OVERLAY (BASIC,1,2)                                               012910
      PROGRAM LINEZ                                                     012920
      REAL L                                                            012930
      COMPLEX Z,Z0,ZN,ZZ,ZZ0,Y                                          012940
      INTEGER PH,C,SB,EB,CON,CHG,SCOP,OUT,CH,CONEC                      012950
      COMMON /COMA/CON,CHG,LODOP,SCOP,INP,OUT,F,T,BKVA,RHO1,NMAX,MAXTR, 012960
     1MAXLTC,MAXPH,ISYS,BKVA1                                           012970
      COMMON /COMB/LINA(1450),LINB(1450),G(1450),B(1450),P(250),Q(250), 012980
     1,PHB(50),PHANG(50),LTRA(250),LTRB(250),TAP(250),TMN(250),V(250),  012990
     2TMX(250),IUBPP(250),ANG(250),IBUS(250),OBP(250),USP(3000),        013000
     3BUSNAME(250),LPHA(50),LIST(250),IUBP(250),QMIN(250),QMAX(250),    013010
     4OBPP(250),UBPP(3000),JBP(3000),JBPP(3000),ICC(250),DLP(250),      013020
     5Z0I(1450),Z0R(1450),BDIA(250),CONEC(250),DLQ(250),IPHASE(250)     013030
      COMMON/COMC/ NA(250),NB(250),JCOL(1000),OU(1000),IOB(250)         013040
      COMMON /CONST/ NBUS,NL,ISS,IPV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC      013050
     1,ITR1,ITR2,PTOL,QTOL,NLC                                          013060
      COMMON /SAVE/IERR                                                 013070
 1000 FORMAT(2I3,F5.0,I2,I1,5F6.0,F4.0,3F5.0,I2,I2,2F6.0,I1)            013080
 1001 FORMAT(1X,"INPUT CODE ERROR!  'ID' DATA CODE NOT COMPATIBLE WITH" 013090
     1" 'C' CODE. LINE CARD NO. ",I3," WITH SB=",I3," AND EB=",I3/)     013100
 1002 FORMAT(1X,"ERROR ON LINE CARD NO.",I3," WITH SB=",I3," AND EB=",I3013110
     1,".",/1X,"VALUES VP,ID OR PH NOT VALID."/)                        013120
 1003 FORMAT(1X,"ERROR HAS RESULTED IN POSITIVE AND ZERO SEQUENCE IMPEDA013130
     1NCES= ZERO.  CHECK DATA ENTRIES ON CARD NUMBER",I5/)              013140
 1004 FORMAT(1X,"NUMBER OF LTC'S INPUT EXCEEDS MAXLTC= ",I5,      "LINE 013150
     1DATA CARD NUMBER ",I5/)                                           013160
 1005 FORMAT(1X,"NUMBER OF LINES INPUT HAS EXCEEDED NMAX=",I5,".  LINE I013170
     1NPUT DATA CARD NUMBER=",I5/)                                      013180
 1006 FORMAT(1X,"NUMBER OF PHASE-SHIFTERS HAS EXCEEDED MAXPH=",I5,".  LI013190
     1NE INPUT DATA CARD NUMBER=",I5/)                                  013200
 1007 FORMAT(1X,"NUMBER OF TRANSFORMERS HAS EXCEEDED MAXTR=",I5,".  LINE013210
     1 DATA CARD NUMBER=",I5/)                                          013220
 1019 FORMAT(///1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,T29,"LINEZ SUBROUTINE" 013230
     1,T71,1H*/1X,1H*,T20,"ASSEMBLED INPUT LINE DATA  (OHMS)",T71,1H*/  013240
     21X,1H*,68X,1H*/1X,70(1H*)//)                                      013250
 1020 FORMAT(///1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,T29,"LINEZ SUBROUTINE",013260
     1T71,1H*/1X,1H*,T19,"ASSEMBLED INPUT LINE DATA  (PER-UNIT)",T71,   013270
     21H*/1X,1H*,68X,1H*/1X,70(1H*)//)                                  013280
 1021 FORMAT(5X,"CONDUCTOR NO. ",I3/5X,"FROM - TO",5X,"RE(Z)",8X,"IM(Z)"013290
     1,8X,"RE(Z0)",7X,"IM(Z0)"/5X,I3,2X,I3,3X,4(F10.4,3X)/)             013300
 1022 FORMAT(5X,"TRANSFORMER, FIXED NO. ",I3/5X,"FROM - TO",5X,"RE(Z)", 013310
     18X,"IM(Z)",8X,"RE(Z0)",7X,"IM(Z0)"/5X,I3,2X,I3,3X,                013320
     24(F10.4,3X)/5X,"TAP",5X,"CONEC CODE"/3X,F7.5,6X,I3/)              013330
 1023 FORMAT(5X,"TRANSFORMER, AUTO. NO. ",I3/5X,"FROM - TO",5X,"RE(Z)", 013340
     18X,"IM(Z)",8X,"RE(Z0)",7X,"IM(Z0)"/5X,I3,2X,I3,3X,                013350
     24(F10.4,3X)/3X,"TAP",5X,"CONEC CODE"/2X,F5.3,5X,I3/)              013360
 1024 FORMAT(5X,"TRANSFORMER, LTC NO. ",I3/5X,"FROM - TO",5X,"RE(Z)",   013370
     18X,"IM(Z)",8X,"RE(Z0)",7X,"IM(Z0)"/5X,I3,2X,I3,3X,4(F10.4,3X)/5X, 013380
     2"TAP",7X,"TMN",7X,"TMX",5X,"CONEC CODE"/3X,3(F7.5,3X),3X,I3/)     013390
 1025 FORMAT(5X,"TRANSFORMER, PHASE-SHIFTER NO. ",I3/5X,"FROM - TO",5X, 013400
     1"RE(Z)",8X,"IM(Z)",8X,"RE(Z0)",7X,"IM(Z0)"/6X,I3,2X,I3,3X,        013410
     24(F10.4,3X)/5X,"TAP",7X,"PHANG",5X,"CONEC CODE"/3X,F7.5,3X,F9.4,  013420
     35X,I3/)                                                           013430
 1026 FORMAT(5X,"SERIES CAPACITOR NO. ",I3/5X,"FROM - TO",5X,           013440
     1"RE(Z)",8X,"IM(Z)",9X,"RE(Z0)",7X,"IM(Z0)"/6X,I3,2X,I3,3X,        013450
     24(F10.4,3X)/)                                                     013460
 1027 FORMAT(5X,"SERIES REACTOR NO. ",I3/5X,"FROM - TO",5X,"RE(Z)",     013470
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     19X,"IM(Z)",8X,"RE(Z0)",7X,"IM(Z0)"/5X,I3,2X,I3,3X,4(F10.4,3X)/)   013480
1020 FORMAT(3X,"ERROR WITH INPUT DATA.  LINE",I3," TO",I3," MUST HAVE    013490
    1SOME IMPEDANCE VALUE OTHER THAN ZERO."/)                             013500
     N=NL=NOTR=NOPH=NOLTC=LL1=LL2=LL3=LL4=0                               013510
     IF(OUT.EQ.1) GO TO 2                                                 013520
     IF(OUT.EQ.2.OR.OUT.EQ.3.OR.OUT.EQ.5.OR.OUT.EQ.8) GO TO 10            013530
     IF(OUT.EQ.10) GO TO 10                                               013540
     WRITE(1,1020)                                                        013550
     GO TO 10                                                             013560
   2 WRITE(1,1019)                                                        013570
  10 READ(5,1000) SB,EB,VP,ID,PH,L,ZZ,ZZ0,PHI,TPI,TMNN,TMXX,C,IUNIT,ZN    013580
    1,C4                                                                  013590
     IF(EB.EQ.0) GO TO 330                                                013600
C  THE FOLLOWING 3 STATEMENTS BLOCK TXFR C CODES 6 TO 10 FOR              013610
C  FIXED,TCUL AND AUTO TXFRS, CODES 6-10 ARE FOR 3 WINDING TXFRS.         013620
     IF(C.GT.5.AND.ID.EQ.5) GO TO 900                                     013630
     IF(C.GT.5.AND.ID.EQ.6) GO TO 900                                     013640
     IF(C.GT.5.AND.ID.EQ.7) GO TO 900                                     013650
     N=N+1                                                                013660
     IF(VP.EQ.0.OR.ID.EQ.0.OR.PH.EQ.0) GO TO 858                          013670
     NL=NL+2                                                              013680
     IF(NL.GT.NMAX) GO TO 855                                             013690
     Z1=CABS(ZZ)                                                          013700
     Z2=CABS(ZZ0)                                                         013710
     IF(Z1.EQ.0.AND.Z2.EQ.0) GO TO 853                                    013720
     IF(ID.GT.4.AND.ID.LT.9) GO TO 20                                     013730
     IF(ID.EQ.9) GO TO 30                                                 013740
     IF(ID.EQ.10) GO TO 35                                                013750
     LL1=LL1+1                                                            013760
     IF(L.EQ.0) L=1.0                                                     013770
     Z=ZZ*L                                                               013780
     IF(ZZ0.NE.0) GO TO 15                                                013790
     IF(TPI.NE.0) GO TO 14                                                013800
     ZZ0=3.5*ZZ                                                           013810
     GO TO 15                                                             013820
  14 ZZ0=2.7*ZZ                                                           013830
  15 Z0=ZZ0*L                                                             013840
     .=0.                                                                 013850
     GO TO 900                                                            013860
  20 NOTR=NOTR+1                                                          013870
     IF(L.EQ.0.AND.IUNIT.GE.1) L=BKVA                                     013880
     IF(IUNIT.EQ.2) ZZ=ZZ*BKVA/L                                          013890
     IF(IUNIT.EQ.2) ZZ0=ZZ0*BKVA/L                                        013900
     IF(NOTR.GT.MAXTR) GO TO 857                                          013910
     IF(TPI.EQ.0) TPI=1.0                                                 013920
     .=0.                                                                 013930
     GO TO(800,800,800,900,21,22,23,24,800,800) ID                        013940
  21 Z=ZZ                                                                 013950
     ZZ0=ZZ0+3*ZN                                                         013960
     IF(ZZ0.EQ.0.) ZZ0=ZZ                                                 013970
     Z0=ZZ0                                                               013980
     LL2=LL2+1                                                            013990
     IADD=40                                                              014000
     GO TO 900                                                            014010
  22 LL3=LL3+1                                                            014020
     IADD=60                                                              014030
     Z=ZZ                                                                 014040
```

```
      ZZ0=ZZ0+3*ZN
      IF(ZZ0.EQ.0.) ZZ0=ZZ
      Z0=ZZ0
      GO TO 900
   23 NOLTC=NOLTC+1
      IF(NOLTC.GT.MAXLTC) GO TO 854
      IF(TMNN.EQ.0) TMNN=.9
      IF(TMXX.EQ.0) TMXX=1.1
      IADD=70
      Z=ZZ
      ZZ0=ZZ0+3*ZN
      IF(ZZ0.EQ.0.) ZZ0=ZZ
      Z0=ZZ0
      GO TO 900
   24 NOPH=NOPH+1
      LL4=NOPH/2
      IF(LL4.GT.MAXPH) GO TO 855
      IADD=90
      Z=ZZ
      ZZ0=ZZ0+3*ZN
      IF(ZZ0.EQ.0.) ZZ0=ZZ
      Z0=ZZ0
      GO TO 900
   30 NOCAP=NOCAP+1
      IF(IUNIT.EQ.2) ZZ=ZZ*BKVA/L
      L=0.
      Z=ZZ
      IF(ZZ0.EQ.0) ZZ0=ZZ
      Z0=ZZ0
      GO TO 900
   35 NOREAC=NOREAC+1
      IF(IUNIT.EQ.2) ZZ=ZZ*BKVA/L
      L=0.
      Z=ZZ
      IF(ZZ0.EQ.0) ZZ0=ZZ
      Z0=ZZ0
      GO TO 900
  800 WRITE(2,1001) N,SB,EB
      GO TO 899
  853 WRITE(2,1003) N
      IERR=IERR+1
      GO TO 10
  854 WRITE(2,1004) MAXLTC,N
      GO TO 899
  855 WRITE(2,1005) NMAX,N
      GO TO 899
  856 WRITE(2,1006) MAXPH,N
      GO TO 899
  857 WRITE(2,1007) MAXTR,N
      GO TO 899
  858 WRITE(2,1002) N,SB,EB
  899 IERR=IERR+1
      RETURN
  900 IF(OUT.EQ.1.AND.IUNIT.GE.1) Z=Z*VP*VP*1000/BKVA
      IF(OUT.EQ.1.AND.IUNIT.GE.1) Z0=Z0*VP*VP*1000/BKVA
      IF(OUT.EQ.1) GO TO 901
      IF(IUNIT.EQ.0) CALL PERUNIT(Z,Z0,PH,VP,L)
```

```
      IF(OUT.EQ.10) GO TO 909                                           014620
      IF(OUT.EQ.2.OR.OUT.EQ.3.OR.OUT.EQ.5.OR.OUT.EQ.8) GO TO 909        014630
  901 GO TO(902,902,902,902,903,904,905,906,907,908) ID                 014640
  902 WRITE(1,1021) LL1,SB,EB,Z,Z0                                      014650
      GO TO 909                                                         014660
  903 WRITE(1,1022) LL2,SB,EB,Z,Z0,TPI,C                                014670
      GO TO 909                                                         014680
  904 WRITE(1,1023) LL3,SB,EB,Z,Z0,TPI,C                                014690
      GO TO 909                                                         014700
  905 WRITE(1,1024) NOLTC,SB,EB,Z,Z0,TPI,TMNN,TMXX,C                    014710
      GO TO 909                                                         014720
  906 WRITE(1,1025) LL4,SB,EB,Z ,Z0,PHI                                 014730
  907 WRITE(1,1026) NOCAP,SB,EB,Z,Z0                                    014740
      GO TO 909                                                         014750
  908 WRITE(1,1027) NOREAC,SB,EB,Z,Z0                                   014760
  909 IF(OUT.EQ.1 ) CALL PERUNIT(Z,Z0,PH,VP,L)                          014770
      IF(IPHASE(SB).NE.3.AND.SB.NE.0) IPHASE(SB)=PH                     014780
      IF(IPHASE(EB).NE.3) IPHASE(EB)=PH                                 014790
      LINA(NL)=EB                                                       014800
      LINB(NL)=SB                                                       014810
      LINA(NL-1)=SB                                                     014820
      LINB(NL-1)=EB                                                     014830
      IF(PHI.EQ.0) GO TO 910                                            014840
      LPHA(NOPH)=EB                                                     014850
      LPHB(NOPH)=SB                                                     014860
      LPHA(NOPH-1)=SB                                                   014870
      LPHB(NOPH-1)=EB                                                   014880
      PHANG(NOPH-1)=PHI*.01745329                                       014890
      PHANG(NOPH)=-PHANG(NOPH-1)                                        014900
  910 IF(ID.LT.5.OR.ID.GT.8) GO TO 920                                  014910
      LTRA(NOTR)=SB                                                     014920
      LTRB(NOTR)=EB                                                     014930
      TAP(NOTR)=TPI                                                     014940
      TMN(NOTR)=TMNN                                                    014950
      TMX(NOTR)=TMXX                                                    014960
      ICD(NOTR)=C+IADD                                                  014970
  920 IF(Z.EQ.0.) GO TO 960                                             014980
      Y=1./Z                                                            014990
      G(NL)=REAL(Y)                                                     015000
      B(NL)=AIMAG(Y)                                                    015010
      Z0R(NL)=REAL(Z0)                                                  015020
      Z0I(NL)=AIMAG(Z0)                                                 015030
      G(NL-1)=G(NL)                                                     015040
      B(NL-1)=B(NL)                                                     015050
      Z0R(NL-1)=Z0R(NL)                                                 015060
      Z0I(NL-1)=Z0I(NL)                                                 015070
      GO TO 10                                                          015080
  930 IF(IERR.NE.0) RETURN                                              015090
      CALL LSORT(2,LINA,LINB,NL,4,G,B,Z0R,Z0I,0)                        015100
      CALL LSORT(2,LTRA,LTRB,NOTR,5,TAP,TMN,TMX,0,ICD)                  015110
      CALL LSORT(2,LPHA,LPHB,NOPH,1,PHANG,0,0,0,0)                      015120
      DO 945 I=1,250                                                    015130
C     IZ=NUMBER OF CONNECTIONS TO REF BUS                               015140
  945 CONEC(I)=0                                                        015150
      IZ=0                                                              015160
      J=1                                                               015170
      DO 950 I=1,NL                                                     015180
```

```
      IF(LINA(I).EQ.0) GO TO 947
  948 IF(LINA(I).NE.J) GO TO 949
      CONEC(J)=CONEC(J)+1
      GO TO 950
  949 J=J+1
      GO TO 948
  947 IZ=IZ+1
  950 CONTINUE
      NBUS=J
      RETURN
  960 WRITE(2,1028) SB,EB
      IERR=IERR+1
      RETURN
      END

      OVERLAY(LODFLO,2,0)
      PROGRAM FDLFLOW
      COMPLEX Y,VA,VB,S,R
      INTEGER CON,CHG,SCOP,OUT,CONEC,A,C
      DIMENSION IDUM(50)
      COMMON /COMA/CON,CHG,LODOP,SCOP,INP,OUT,F,T,BKVA,RHO1,NMAX,MAXTR,
     1MAKLTC,MAXPH,ISYS,BKVA1
      COMMON /COMB/LINA(1450),LINB(1450),G(1450),B(1450),P(250),Q(250),
     1LPHB(50),PHANG(50),LTRA(250),LTRB(250),TAP(250),TMN(250),V(250),
     2TMX(250),IUBPP(250),ANG(250),IBUS(250),DBP(250),UBP(3000),
     3BUSNAME(250),LPHA(50),LIST(250),IUBP(250),QMIN(250),QMAX(250),
     4DBPP(250),UBPP(3000),JBP(3000),JBPP(3000),ICC(250),DLP(250),
     5ZOI(1450),ZOR(1450),ROIA(250),CONEC(250),DLQ(250),IPHASE(250)
      COMMON/COMC/ NA(250),NB(250),JCOL(1000),DU(1000),IDR(250)
      COMMON/CONST/ NBUS,NL,ISS,IRV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC
     1,ITR1,ITR2,PTOL,QTOL,NLC
      COMMON/SUB/ BM
 1000 FORMAT(/T16,"**** CONVERGENCE NOT OBTAINED IN:"/20X,I4,
     1" DELTA THETA AND"/20X,I4," DELTA V ITERATIONS."//1X,
     2"BUS NO.",3X,"VOLT(MAG)",3X,"VOLT(ANG)",5X,"DELTA P",7X,
     3"DELTA Q"/)
 1001 FORMAT(/1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,T30,
     1"SYSTEM SUMMARY",T71,1H*/1X,1H*,68X,1H*/1X,1H*,T25,
     2"CONVERGENCE OBTAINED IN:",T71,1H*/1X,1H*,T24,I4,1X,
     3"DELTA THETA AND",T71,1H*/1X,1H*,T24,I4,1X,
     4"DELTA V ITERATIONS.",T71,1H*/1X,1H*,T71,1H*/1X,70(1H*)/)
 1002 FORMAT(//1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,T27,"CALCULATED LINE FLO
     1WS",T71,1H*/1X,1H*,T4,"(THE LINE FLOWS ARE DEFINED POSITIVE WHEN F
     2LOWING OUT FROM THE BUS)",T71,1H*/1X,1H*,68X,1H*/1X,70(1H*)//T5,
     3"LINE",T22,"POWER",15X,"LINE",12X,"POWER"/2X,"FROM",2X,"TO",
     45X,"REAL",7X,"REACTIVE",5X,"FROM",2X,"TO",5X,"REAL",7X,
     5"REACTIVE"/)
 1003 FORMAT(1X,2(I3,2X),1X,F9.5,3X,F9.5,5X,I3,2X,I3,2(3X,F9.5)/)
 1004 FORMAT(T23,"****** SLACK BUS POWER ******"/T10,"BUS NO.",T24,
     1"REAL",T37,"REACTIVE",T55,"MAG."//10X,I3,7X,F10.5,5X,F10.5,6X,
     2F9.5//)
 1005 FORMAT(///1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,T14,"RESULTS OF FAST DE
     1COUPLED LOAD FLOW ANALYSIS",T71,1H*/1X,1H*,
     2T19,"ALL MAGNITUDE VALUES ARE PER-UNIT",T71,1H*/1X,1H*,
     3T19,"SYSTEM HAS ",I3," BUSES: ",I2," ARE TYPE 2.",T71,1H*/1X,
     41H*,T10,"NUMBER OF TIMES LOAD BUSES WILL BE CHANGED(NLC)=",
     5I3,".",T71,1H*/1X,1H*,T26,"CONVERGENCE TOLERANCES:",T71,1H*/
     61X,1H*,T31,"PTOL=",F7.5,T71,1H*/1X,1H*,T31,"QTOL=",F7.5,T71,1H*/
     71X,1H*,68X,1H*/1X,70(1H*)//)
 1006 FORMAT(//1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,T25,"OUTPUT TRANSFORMER
     1DATA",T71,1H*/1X,1H*,68X,1H*/1X,70(1H*)//T14,"SB",T19,"EB",T27,
     2"TAP",T36,"TAP(MIN)",T50,"TAP(MAX)"//(12X,I3,2X,I3,4X,F7.5,4X,
     3F7.5,7X,F7.5))
 1007 FORMAT(//1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,T23,"OUTPUT PHASE SHIFTE
     1R DATA",T71,1H*/1X,1H*,68X,1H*/1X,70(1H*)//T17,"SB",T22,"EB",T29,
     2"TAP",T37,"PHASE ANGLE(DEG)"//(13X,I3,2X,I3,3X,F7.5,6X,F9.4))
 1008 FORMAT(T58,"POWER"/T3,"NO.",T7,"TYPE",T15,"NAME",T25,"V(MAG)",
     1T35,"V(ANG-DEG)",T53,"REAL",T63,"REACTIVE"//(1X,I3,3X,
     2I1,3X,A10,3X,F7.4,4X,F9.4,4X,F9.5,4X,F9.5))
 1009 FORMAT(//1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,T28,"OUTPUT BUS DATA",
     1T71,1H*/1X,1H*,68X,1H*/1X,70(1H*)//)
 1010 FORMAT(1X,I3,8X,F6.4,5X,F8.4,5X,F8.5,6X,F9.5)
```

```
1011 FORMAT(1X,"BUS",I3," SHOULD HAVE BEEN IN REORDERED BUS LIST,BUT     015900
    1WASN'T.  CHECK INPUT BUS LIST"/)                                   015910
1016 FORMAT(1X,"ERROR: BUS VOLTAGE CALCULATED FOR BUS",I3," IS 0.       015920
    1ERROR IS IN LOAD FLOW ROUTINE WHERE DLP OR DLQ IS CALCULATED."/)   015930
1017 FORMAT(R6,I3)                                                      015940
1018 FORMAT(I2,I3,R10,2F5.0,4F10.0)                                     015950
1019 FORMAT(1X,"ERROR: MAGNITUDE OF SLACK BUS POWER HAS EXCEEDED LIMIT 015960
    1 OF 0 OR 100000 P.U."/)                                            015970
1020 FORMAT(T3,"IDB CAN'T BE GREATER THAN 1 IN LOAD CHANGE ROUTINE      015980
    1SEE BUS",I3," WITH BUSNAME",R10," ."/)                             015990
1021 FORMAT(/1X,70(1H*)/1X,70(1H*)/1X,1H*,T27,"LOAD FLOW BUS CHANGE     016000
    1",T71,1H*/1X,1H*,T28,"CHANGE NUMBER",I3,T71,1H*/1X,1H*,T24         016010
    2,"NUMBER OF BUSES CHANGED",I3,T71,1H*/1X,1H*,68X,1H*/1X,70         016020
    3(1H*)/)                                                            016030
1022 FORMAT(/1X,70(1H*)/1X,1H*,69X,1H*/1X,1H*,T29,"BUS CHANGE DATA      016040
    1",T71,1H*/1X,1H*,69X,1H*/1X,70(1H*)/)                              016050
1023 FORMAT(T3,"PROGRAM CONTROL CARD NOT IN PROPER FORMAT OR LOCATION. 016060
    1CARD WITH KEYWORD ",R6," IS REQUIRED."/)                           016070
1024 FORMAT(1X,I3,2X,I2,4X,R10,2X,F5.3,7X,F5.3,6X,F10.5,3X,F10.5)       016080
     ITRMAX1=ITR1                                                       016090
     ITRMAX2=ITR2                                                       016100
     ITER=ITERR=0                                                       016110
     WRITE(2,1005) NBUS,IPV,NLC,PTOL,QTOL                               016120
C  THE FOLLOWING SECTION TRIANGULATES AND STORES THE ELEMENTS OF        016130
C  THE B' AND B'' MATRICES.  THESE ELEMENTS REMAIN CONSTANT THROUGHOUT  016140
C  THE SOLUTION OF THE MW-THETA, AND MVAR-V EQUATIONS.  THE FIRST       016150
C  PORTION TRIANGULATES B', AND THE SECOND PORTION DOES B'', WHICH      016160
C  DOES NOT HAVE PV BUSSES REPRESENTED.                                 016170
C  THE FOLLOWING LOOP RESTORES THE DUMMY NA VECTOR FOR THE B'           016180
C  TRIANGULATION.                                                       016190
     DO 1 I=1,250                                                       016200
   1 NA(I)=0                                                            016210
     M=J=1                                                              016220
     DO 5 I=1,NL                                                        016230
     IF(LINA(I).EQ.0.OR.LINB(I).EQ.0) GO TO 5                           016240
     JCOL(M)=LINB(I)                                                    016250
     Y=CMPLX(G(I),B(I))                                                 016260
     IF(Y.EQ.0) GO TO 909                                               016270
     IF(Y.EQ.0.) GO TO 909                                              016280
     Y1=AIMAG(1./Y)                                                     016290
     IF(Y1.EQ.0) GO TO 909                                              016300
     IF(Y1.EQ.0.) GO TO 909                                             016310
     DU(M)=-1./AIMAG(1./Y)                                              016320
     M=M+1                                                              016330
   2 IF(LINA(I).NE.J) GO TO 3                                           016340
     NA(J)=NA(J)+1                                                      016350
     GO TO 5                                                            016360
   3 J=J+1                                                              016370
     GO TO 2                                                            016380
   5 CONTINUE                                                           016390
     ISS=NL-2*IZ                                                        016400
     DO 7 I=1,NBUS                                                      016410
     BDIA(I)=BSUM=0.                                                    016420
     IAB=JADD(I)                                                        016430
     IAC=IAB+NA(I)-1                                                    016440
        DO 6 J=IAB,IAC                                                  016450
        BSUM=BSUM+DU(J)                                                 016460
```

```
    6       CONTINUE                                                    016470
      BDIA(I)=-BSUM                                                     016480
    7 CONTINUE                                                          016490
C   THE FOLLOWING DO 100 LOOP TRIANGULATES THE B' MATRIX.  THE ORDER OF 016500
C   TRIANGULATION FOLLOWS THE REORDERED BUS LIST (NB(X)) RETURNED BY    016510
C   SUBROUTINE ORDER.  THE SLACK BUS IS NOT REPRESENTED IN B', AND IS   016520
C   PASSED OVER IN THE TRIANG. PROCESS.  THE FIRST INNER LOOP IDENTIFIES 016530
C   ALL ROWS BELOW THE I'TH ROW THAT WILL BE AFFECTED BY THE I'TH ROW   016540
C   ELIMINATION.  THE FOLLOWING STATEMENTS AND SECOND INNER LOOP STORE  016550
C   THE DIAGONAL AND UPPER-TRIANGULAR TERMS FOR THE I'TH ROW.  THE DBP(K)016560
C   VECTOR CONTAINS A LIST OF THE DIAG. TERMS, AND THE IUBP(K) VECTOR   016570
C   CONTAINS A LIST OF POINTERS TO THE FIRST ELEMENT OF THE UPPER-      016580
C   TRIANGULAR LIST UBP(KK) ASSOCIATED WITH THE I'TH ROW.  THE JBP(KK)  016590
C   VECTOR CONTAINS A LIST OF COLUMN IDENTIFIERS CORRESPONDING TO EACH  016600
C   TERM IN THE UBP(KK) VECTOR.  THE INNER DO 50 LOOP COMPLETES THE     016610
C   ELIMINATION PROCESS ON THE ROWS BELOW THE I'TH ROW.  THE I'TH COLUMN 016620
C   ELEMENT IS DELETED FROM THE N'TH ROW (DO 30 LOOP), AND THEN AN      016630
C   ELEMENT-BY-ELEMENT COMPARISON IS MADE BETWEEN THE I'TH AND N'TH ROWS.016640
C   N'TH ROW TERMS ARE MODIDIED, OR NEW TERMS ADDED AS APPROPRIATE      016650
C   (DO 32 LOOP).                                                       016660
      K=KK=1                                                            016670
      DO 100 I=1,NBUS                                                   016680
      IRW=NB(I)                                                         016690
      IF(IDB(IRW).EQ.3) GO TO 100                                       016700
      DBP(K)=1./BDIA(IRW)                                               016710
      IUBP(K)=KK                                                        016720
      IF(I.EQ.NBUS) GO TO 100                                           016730
      KKK=0                                                             016740
            DO 10 M=1,ISS                                               016750
            IK=IRN(M)                                                   016760
            IF(IDB(IK).EQ.3.OR.JCOL(M).NE.IRW) GO TO 10                 016770
                  DO 9 LM=1,I                                           016780
                  IF(IK.EQ.NB(LM)) GO TO 10                             016790
    9             CONTINUE                                              016800
            KKK=KKK+1                                                   016810
            IDUM(KKK)=IK                                                016820
   10       CONTINUE                                                    016830
      KI=JADD(IRW)                                                      016840
      KF=KI+NA(IRW)-1                                                   016850
      IF(KF.LT.KI) GO TO 16                                             016860
      ITEST=KK                                                          016870
            DO 15 J=KI,KF                                               016880
            IF(IDB(JCOL(J)).EQ.3) GO TO 15                              016890
            DU(J)=DU(J)*DBP(K)                                          016900
            UBP(KK)=-DU(J)                                              016910
            JBP(KK)=JCOL(J)                                             016920
            KK=KK+1                                                     016930
   15       CONTINUE                                                    016940
   16 K=K+1                                                             016950
      IF(KK.NE.ITEST) GO TO 17                                          016960
      UBP(KK)=0.                                                        016970
      JBP(KK)=0                                                         016980
      KK=KK+1                                                           016990
   17 IF(KKK.EQ.0) GO TO 100                                            017000
            DO 50 N=1,KKK                                               017010
            IJJ=0                                                       017020
   20       KI=JADD(IRW)                                                017030
```

```
                 KF=KI+NA(IRN)-1
                      DO 40 J=KI,KF
                      IF(IDB(JCOL(J)).EQ.3) GO TO 40
                      K1=JADD(IDUM(N))
                      K2=K1+NA(IDUM(N))-1
                 IF(K2.LT.K1) GO TO 34
                      IF(IJJ.EQ.1) GO TO 31
                           DO 30 L=K1,K2
                           IF(JCOL(L).EQ.IRN) GO TO 35
      30                   CONTINUE
      31              IF(IRN(K1).EQ.JCOL(J)) GO TO 36
                           DO 32 L=K1,K2
                           IF(JCOL(L).EQ.JCOL(J)) GO TO 39
      32                   CONTINUE
                      CALL ADROL(L-1,1,J)
                      NA(IDUM(N))=NA(IDUM(N))+1
                      GO TO 40
      35              BM=DU(L)
                      CALL ADROL(L,-1,0)
                      IJJ=1
                      NA(IDUM(N))=NA(IDUM(N))-1
                      GO TO 20
      36              BDIA(IRN(K1))=BDIA(IRN(K1))-BM*DU(J)
                      GO TO 40
      34              BDIA(IRN(K1)-1)=BDIA(IRN(K1)-1)-BM*DU(J)
                      GO TO 40
      39              DU(L)=DU(L)-BM*DU(J)
      40              CONTINUE
      50         CONTINUE
     100 CONTINUE
C  THE FOLLOWING DO 200 LOOP TRIANGULATES B'' IN THE SAME MANNER AS B'
C  ABOVE, EXCEPT THAT PV BUSSES ARE NOT REPRESENTED IN B''.
         DO 101 I=1,250
     101 NA(I)=0
         M=J=1
         DO 105 I=1,NL
         IF(LINA(I).EQ.0) GO TO 105
         JCOL(M)=LINB(I)
         DU(M)=B(I)
         M=M+1
     102 IF(LINA(I).NE.J) GO TO 103
         NA(J)=NA(J)+1
         GO TO 105
     103 J=J+1
         GO TO 102
     105 CONTINUE
         ISS=NL-IZ
         DO 107 I=1,NBUS
         BDIA(I)=BSUM=0.
         IAB=JADD(I)
         IAC=IAB+NA(I)-1
              DO 106 J=IAB,IAC
              BSUM=BSUM+DU(J)
     106      CONTINUE
         BDIA(I)=-BSUM
     107 CONTINUE
         K=KK+1
```

```
      DO 200 I=1,NBUS
      IRW=NB(I)
      IF(IDB(IRW).NE.1) GO TO 200
      DBPP(K)=1./BDIA(IRW)
      IUBPP(K)=KK
      IF(I.EQ.NBUS) GO TO 200
      KKK=0
         DO 110 M=1,ISS
         IK=IRN(M)
         IF(IDB(IK).NE.1.OR.JCOL(M).NE.IRW) GO TO 110
            DO 109 LM=1,I
            IF(IK.EQ.NB(LM)) GO TO 110
109         CONTINJE
         KKK=KKK+1
         IDUM(KKK)=IK
110      CONTINUE
      ITEST=KK
      KI=JADD(IRW)
      KF=KI+NA(IRW)-1
      IF(KF.LT.KI) GO TO 116
         DO 115 J=KI,KF
         IF(IDB(JCOL(J)).NE.1) GO TO 115
         DU(J)=DU(J)*DBPP(K)
         UBPP(KK)=-DJ(J)
         JBPP(KK)=JCOL(J)
         KK=KK+1
115       CONTINUE
116   K=K+1
      IF(KK.NE.ITEST) GO TO 117
      UBPP(KK)=0.
      JBPP(KK)=0
      KK=KK+1
117   IF(KKK.EQ.0) GO TO 200
         DO 150 N=1,KKK
         IJJ=0
120      KI=JADD(IRW)
         KF=KI+NA(IRW)-1
            DO 140 J=KI,KF
            IF(IDB(JCOL(J)).NE.1) GO TO 140
            K1=JADD(IDUM(N))
            K2=K1+NA(IDUM(N))-1
         IF(K2.LT.K1) GO TO 134
            IF(IJJ.EQ.1) GO TO 131
               DO 130 L=K1,K2
               IF(JCOL(L).EQ.IRW) GO TO 135
130            CONTINUE
131         IF(IRN(K1).EQ.JCOL(J)) GO TO 135
               DO 132 L=K1,K2
               IF(JCOL(L).EQ.JCOL(J)) GO TO 139
132            CONTINUE
            CALL ADROL(L-1,1,J)
            NA(IDUM(N))=NA(IDUM(N))+1
            GO TO 140
135         DM=DJ(L)
            CALL ADROL(L,-1,0)
            NA(IDUM(N))=NA(IDUM(N))-1
            IJJ=1
```

```
          GO TO 120
136       BDIA(IRN(K1))=BDIA(IRN(K1))-BM*DU(J)
          GO TO 140
134       BDIA(IRN(K1)-1)=BDIA(IRN(K1)-1)-BM*DU(J)
          GO TO 140
139       DU(L)=DU(L)-BM*DU(J)
140       CONTINUE
150    CONTINUE
200 CONTINUE
    DO 209 I=1,NBUS
    LIST(I)=0
209 NA(I)=CONEC(I)
C  THE FOLLOWING SECTIONS ARE THE DIRECT SOLUTION ALGORITHM:
C  STATEMENT 211 IS THE ENTRY POINT FOR THE DELTA-P/DELTA THETA
C  SOLUTION.  THE DLP ARRAY IS FORMED AS:  P(SPEC)/V - P(CALC)/V,
C  AND THEN SOLVED FOR DELTA THETA.  THE DELTA THETA SOLUTION FOR
C  EACH BUS IS THE DLP ARRAY AFTER THE FORWARD AND BACKWARD SUBSTI-
C  TUTIONS.  THE DELTA THETA IS ADDED TO THE EXISTING BUS ANGLE TO
C  UPDATE THE BUS ANGLE AFTER EACH SOLUTION.
C  STATEMENT 291 IS THE ENTRY POINT FOR THE DELTA-Q/DELTA V SOLUTION.
C  THE DLQ ARRAY PERFORMS THE SAME FUNCTION AS DLP ABOVE, EXCEPT
C  THAT THE SOLUTION DELTA V IS THE RESULTING ARRAY.  THE DELTA V
C  FOR EACH BUS IS ADDED TO THE EXISTING BUS VOLTAGE MAGNITUDE TO
C  FORM THE UPDATED BUS V MAG. FOLLOWING EACH SOLUTION ITERATION.
210 KP=KQ=1
211 KP=0
    K=0
    DO 250 I=1,NBUS
    IRW=NB(I)
    IF(IDB(IRW).EQ.3) GO TO 250
    K=K+1
    II=JADD(IRW)+IZ
    IF=II+CONEC(IRW)-1
    GS=BSUM=0.
       DO 225 J=II,IF
       T=TAPR(IRW,LINB(J))
       GS=GS+T*G(J)
       IF(LINB(J).EQ.0) GO TO 225
       THETA=ANG(IRW)-ANG(LINB(J))
       IF(THETA.GT.94.2) THETA=94.2
       IF(THETA.LT.-94.2) THETA=-94.2
       BSUM=BSUM+V(LINB(J))*(-G(J)*COS(THETA)-B(J)*SIN(THETA))
225    CONTINUE
    PC=V(IRW)*(BSUM+V(IRW)*GS)
    IF(V(IRW).EQ.0) GO TO 906
    IF(V(IRW).EQ.0.) GO TO 906
    DLP(K)=P(IRW)/V(IRW)-PC/V(IRW)
    DELTA=ABS(DLP(K))
    IF(DELTA.GT.PTOL) KP=1
250 CONTINUE
    IF(KP.EQ.0) GO TO 400
    IF(ITER.GT.ITRMAX1) GO TO 500
    IS=NBUS-2
    DO 270 I=1,IS
    K1=IUBP(I)
    K2=IUBP(I+1)-1
       DO 265 J=K1,K2
```

```
            IF(JBP(J).EQ.0) GO TO 265
            JJ=IPOS(JBP(J))
            DLP(JJ)=DLP(JJ)+UBP(J)*DLP(I)
  265       CONTINUE
  270 CONTINUE
      DO 275 I=1,K
  275 DLP(I)=DLP(I)*DRP(I)
      DO 295 I=1,IS
      TEMP=0.
      K1=IUBP(K-I)
      K2=IJBP(K-I+1)-1
            DO 280 J=K1,K2
            IF(JBP(J).EQ.0) GO TO 280
            JJ=IPOS(JBP(J))
            TEMP=TEMP+UBP(J)*DLP(JJ)
  280       CONTINUE
      DLP(K-I)=DLP(K-I)+TEMP
  285 CONTINUE
      DO 290 I=1,NBUS
      IF(IDB(I).EQ.3) GO TO 290
            M=0
            DO 288 J=1,NBUS
            IF(IDB(NB(J)).EQ.3) GO TO 288
            M=M+1
            IF(NB(J).EQ.I) GO TO 289
  288       CONTINUE
  289 ANG(I)=ANG(I)+DLP(M)
      IF(ANG(I).GT.94.26) ANG(I)=94.26
      IF(ANG(I).LT.-94.25) ANG(I)=-94.26
  290 CONTINUE
      ITER=ITER+1
C  STATEMENT 291 IS THE ENTRY POINT FOR THE DELTA Q-DELTA V SOLUTION
C  ROUTINE.  ITERR IS THE ITERATION COUNTER FOR THIS ROUTINE.  THE
C  DO 350 LOOP FORMS THE DELTA Q/V VECTOR FOR THE CURRENT ITERATION.
C  IF KQ=0 AT THE END OF THIS LOOP, DQ-DV CONVERGENCE IS OBTAINED.
C  OTHERWISE, THE DO 370 THROUGH DO 393 LOOPS SOLVE FOR THE NEW DELTA V.
C  THE DO 390 LOOP UPDATES THE BUS VOLTAGES.
  291 KQ=0
      K=0
      DO 350 I=1,NBUS
      IRW=NR(I)
      IF(IDB(IRW).NE.1) GO TO 350
      K=K+1
      II=JADD(IRW)+IZ
      IF=II+CONEC(IRW)-1
      BS=BSUM=0.
            DO 325 J=II,IF
            T=TAPR(IRW,LINB(J))
            BS=BS+T*B(J)
            IF(LINB(J).EQ.0) GO TO 325
            THETA=ANG(IRW)-ANG(LINB(J))
            IF(THETA.GT.6.3) THETA=6.3
            IF(THETA.LT.-6.3) THETA=-6.3
            BSUM=BSUM+V(LINB(J))*(-G(J)*SIN(THETA)+B(J)*COS(THETA))
  325       CONTINUE
      QC=V(IRW)*(BSUM-V(IRW)*(BS))
      IF(V(IRW).EQ.0.) GO TO 905
```

```
      IF(V(IRW).EQ.0) GO TO 906
      DLQ(K)=Q(IRW)/V(IRW)-QC/V(IRW)
      DELTA=ABS(DLQ(K))
      IF(DELTA.GT.QTOL) KQ=1
  350 CONTINUE
      IF(KQ.EQ.0) GO TO 401
      IF(ITERR.GT.ITRMAX2) GO TO 500
      IS=K-1
      DO 370 I=1,IS
      K1=IUBPP(I)
      K2=IUBPP(I+1)-1
          DO 365 J=K1,K2
          IF(JBPP(J).EQ.0) GO TO 365
          JJ=IPOSI(JBPP(J))
          DLQ(JJ)=DLQ(JJ)+UBPP(J)*DLQ(I)
  365     CONTINUE
  370 CONTINUE
      DO 375 I=1,K
  375 DLQ(I)=DLQ(I)*DBPP(I)
      DO 385 I=1,IS
      TEMP=0.
      K1=IUBPP(K-I)
      K2=IUBPP(K-I+1)-1
          DO 380 J=K1,K2
          IF(JBPP(J).EQ.0) GO TO 380
          JJ=IPOSI(JBPP(J))
          TEMP=TEMP+UBPP(J)*DLQ(JJ)
  380     CONTINUE
      DLQ(K-I)=DLQ(K-I)+TEMP
  385 CONTINUE
      DO 390 I=1,NBUS
      IF(IDB(I).NE.1) GO TO 390
          M=0
          DO 388 J=1,NBUS
          IF(IDB(NB(J)).NE.1) GO TO 388
          M=M+1
          IF(NB(J).EQ.I) GO TO 389
  388     CONTINUE
  389 CONTINUE
      V(I)=V(I)+DLQ(M)
      IF(V(I).LT.-100.) V(I)=-100.
      IF(V(I).GT.100.) V(I)=100.
  390 CONTINUE
      ITERR=ITERR+1
C  AFTER THE DELTA-V SOLUTION, SUBROUTINE LIMIT IS CALLED TO DETER-
C  MINE IF ANY PV(TYPE 2) BUSSES HAVE EXCEEDED THEIR Q LIMITS.
      CALL LIMIT(0)
      GO TO 211
  400 IF(KQ.EQ.0) 450,291
  401 IF(KP.EQ.0) 450,211
C  CONVERGENCE HAS BEEN OBTAINED.  THE FOLLOWING SECTION CALCULATES
C  THE SLACK BUS POWER, AND  WRITES THE RESULTS ON THE OUTPUT FILE.
  450 WRITE(2,1001) ITER,ITERR
      DO 452 I=1,NBUS
      IF(IDB(I).NE.3) GO TO 452
      KI=JADD(I)+IZ
      KF=KI+CONEC(I)-1
```

```
      GS=BS=SUM=BSUM=0.
          DO 451 J=KI,KF
          T=TAPR(I,LINB(J))
          GS=GS+T*G(J)
          BS=BS+T*B(J)
          IF(LINB(J).EQ.0) GO TO 451
          THETA=ANG(I)-ANG(LINB(J))
          SUM=SUM+V(LINB(J))*(-G(J)*COS(THETA)-B(J)*SIN(THETA))
          BSUM=BSUM+V(LINB(J))*(-G(J)*SIN(THETA)+B(J)*COS(THETA))
  451     CONTINUE
      P(I)=V(I)*(SUM+V(I)*GS)
      Q(I)=V(I)*(BSUM-V(I)*BS)
      SM1=P(I)*P(I)+Q(I)*Q(I)
      IF(SM1.LT.0.) GO TO 910
      IF(SM1.GT.10E9) GO TO 910
      SM=SQRT(SM1)
      WRITE(2,1004) I,P(I),Q(I),SM
      GO TO 453
  452 CONTINUE
  453 IF(OUT.EQ.6.OR.OUT.EQ.10) GO TO 456
C  CALCULATE LINE FLOWS***
      WRITE(2,1002)
      NN=0
      DO 455 I=1,NL
      IF(LINA(I).EQ.0.OR.LINB(I).EQ.0) GO TO 455
      IF(LINA(I).GT.LINB(I)) GO TO 455
      NN=NN+1
      Y=CMPLX(G(I),B(I))
      EA=V(LINA(I))*COS(ANG(LINA(I)))
      EB=V(LINA(I))*SIN(ANG(LINA(I)))
      VA=CMPLX(EA,EB)
      EA=V(LINB(I))*COS(ANG(LINB(I)))
      EB=V(LINB(I))*SIN(ANG(LINB(I)))
      VB=CMPLX(EA,EB)
      DO 454 N=1,NOTR
      IF(LINA(I).NE.LTRA(N)) GO TO 457
      IF(LINB(I).NE.LTRB(N)) GO TO 454
      T=TAP(N)
      IF(T.EQ.0) T=1
      IF(T.EQ.0.) T=1
      S=T*VA*CONJG((T*VA-VB)*Y/T)
      R=VB*CONJG((VB-T*VA)*Y/T)
      GO TO 458
  457 IF(LINA(I).NE.LTRB(N)) GO TO 454
      IF(LINB(I).NE.LTRA(N)) GO TO 454
      T=TAP(N)
      IF(T.EQ.0) T=1
      IF(T.EQ.0.) T=1
      S=VA*CONJG((VA-T*VB)*Y/T)
      R=T*VB*CONJG((T*VB-VA)*Y/T)
      GO TO 458
  454 CONTINUE
C  FALLING OUT THE BOTTOM OF THIS LOOP MEANS THAT THE BRANCH DEFINED
C  BY LINA(I)-LINB(I) IS NOT A TRANSFORMER, AND A TAP CALCULATION IS
C  NOT NECESSARY.  CALCULATE THE LINE POWER FLOWS BELOW:
      S=VA*CONJG((VA-VB)*Y)
      R=VB*CONJG((VB-VA)*Y)
```

```
  458 WRITE(2,1003) LINA(I),LINB(I),S,LINB(I),LINA(I),R
  455 CONTINUE
  456 DO 459 I=1,NBUS
  459 ANG(I)=57.29578*ANG(I)
C  WRITE SUMMARIZED OUTPUT DATA ON OUTPUT FILE:
      WRITE(2,1009)
      WRITE(2,1008) (IBUS(I),IDB(I),BUSNAME(I),V(I),ANG(I),P(I),Q(I),
     1I=1,NBUS)
      IF(OUT.EQ.10) GO TO 570
      IF(LL4.EQ.0.OR.OUT.EQ.9) GO TO 451
      WRITE(2,1007) (LPHA(I),LPHB(I),PHANG(I),I=1,LL4)
  461 IF(NOTR.EQ.0.OR.OUT.EQ.9) GO TO 570
      WRITE(2,1006) (LTRA(I),LTRB(I),TAP(I),TMN(I),TMX(I),I=1,NOTR)
      GO TO 570
  500 WRITE(2,1000) ITER,ITERR
      .ODOP=-1
      DO 501 I=1,NBUS
  501 ANG(I)=57.29578*ANG(I)
C  THIS SECTION TO 502 IS TABLE DUMP ROUTINE WHEN PROBLEM DOES NOT
C  CONVERGE WITHIN SPECIFIED ITERATIONS.
      DO 502 IB=1,NBUS
      IF(IDB(IB).NE.1) GO TO 505
      N1=M1=0
      DO 503 JA=1,NBUS
      IF(IDB(NB(JA)).NE.1) GO TO 503
      N1=N1+1
      M1=M1+1
      IF(NB(JA).EQ.IB) GO TO 519
  503 CONTINUE
      GO TO 900
  505 IF(IDB(IB).EQ.3) GO TO 510
      M2=0
      DO 506 JJJ=1,NBUS
      IF(IDB(NB(JJJ)).EQ.3) GO TO 506
      M2=M2+1
      IF(NB(JJJ).EQ.IB) GO TO 518
  506 CONTINUE
      GO TO 900
  510 DQ=DP=0
      GO TO 520
  518 DP=DLP(M2)
      DQ=0
      GO TO 520
  519 DP=DLP(M1)
      DQ=DLQ(M1)
      GO TO 520
  520 WRITE(2,1010) IBUS(IB),V(IB),ANG(IB),DP,DQ
  502 CONTINUE
      RETURN
  570 CONTINUE
C  LOAD FLOW AUTO CHANGE ROUTINE. THE NUMBER OF CHANGES IS READ(NC)
C  THEN NEW BUS DATA IS READ. BUS LIST UPDATED BY LOOP 600. LOAD
C  FLOW ROUTINE IS AGAIN ENTERED AT 210 AND EXECUTED USING NEW DATA.
C  NLC IS NUMBER OF CHANGE.  NC IS NUMBER OF BUSES EACH CHANGE.
C  NCC IS CHANGE COUNTER.  BUS CARDS USE SAME FORMAT AS IN BUSIN RT.
      IF(NLC.LE.0) GO TO 999
      DO 580 I=1,NBUS
```

```
      ANG(I)=.01745329*ANG(I)
  500 CONTINUE
      NCC=NCC+1
      READ(5,1017) A,NC
      C=6RBUSCHG
      IF(A.NE.C) GO TO 908
      WRITE(2,1021) NCC,NC
      WRITE(2,1022)
      WRITE(2,1008)
      DO 602 IC=1,NC
      READ(5,1018) IDBN,IBUSN,BUSN,VAN,AGN,PAN,QAN,QMINN,QMAXN
      IF(IDBN.GT.1) GO TO 907
      QMINN=QMINN/BKVA
      QMAXN=QMAXN/BKVA
      PN=PAN/BKVA
      QN=QAN/BKVA
      WRITE(2,1024)  IBUSN,IDBN,BUSN,VAN,AGN,PN,QN
      ANGN=.01745329*AGN
      IF(VAN.EQ.0) VAN=1.0
      VN=VAN
        DO 600 JC=1,NBUS
        IF(IBUS(JC).NE.IBUSN) GO TO 600
        P(JC)=PN
        Q(JC)=QN
        QMIN(JC)=QMINN
        QMAX(JC)=QMAXN
        ANG(JC)=ANGN
        V(JC)=VN
        BUSNAME(JC)=BUSN
        IDB(JC)=IDBN
  600   CONTINUE
  602 CONTINUE
      NLC=NLC-1
      GO TO 210
  900 WRITE(2,1011) IB
      GO TO 980
  906 WRITE(2,1016) IRN
      GO TO 980
  907 WRITE(2,1020) IBUSN,BUSN
      GO TO 980
  908 WRITE(2,1023) C
      GO TO 980
  909 WRITE(2,1011) LINA(I)
      GO TO 980
  910 WRITE(2,1019)
  980 IERR=IERR+1
  999 RETURN
      END

      SUBROUTINE ADROL(IJ,IC,J)
C  THIS SUBROUTINE ADDS OR DELETES ENTRIES FROM THE DU AND JCOL
C  TABLES.  OTHER TABLE ENTRIES ARE MOVED TO ALLOW FOR THE ADDED
C  OR DELETED ENTRIES.  THE COUNTER FOR THE NUMBER OF ENTRIES IS
C  ALSO ADJUSTED APPROPRIATELY.
      COMMON/COMC/ NA(250),NB(250),JCOL(1000),DU(1000),IDB(250)
      COMMON/CONST/ NBUS,NL,ISS,IPV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC
     1,ITR1,ITR2,PTOL,QTOL,NLC
      COMMON/SUB/ BM
      IF(IC.EQ.1) GO TO 20
      LS=ISS-1
      DO 10 I=IJ,LS
      JCOL(I)=JCOL(I+1)
      DU(I)=DU(I+1)
   10 CONTINUE
      JCOL(ISS)=0
      DU(ISS)=0.
      ISS=ISS-1
      RETURN
   20 LS=ISS-IJ-2
      BM=DU(J)
      JC=JCOL(J)
      JCOL(ISS+1)=JCOL(ISS)
      DU(ISS+1)=DU(ISS)
      JCOL(ISS)=JCOL(ISS-1)
      DU(ISS)=DU(ISS-1)
      DO 30 I=1,LS
      JCOL(ISS-I)=JCOL(ISS-I-1)
      DU(ISS-I)=DU(ISS-I-1)
   30 CONTINUE
      JCOL(IJ+1)=JC
      DU(IJ+1)=-BM*DM
      ISS=ISS+1
      RETURN
      END
```

```
      SUBROUTINE LIMIT(IDX)
      INTEGER CONEC
      DIMENSION SK(250)
      COMMON /COMA/CON,CHG,LOOOP,SCOP,INP,OUT,F,T,BKVA,RHO1,NMAX,MAXTR,
     1MAXLTC,MAXPH,ISYS,BKVA1
      COMMON /COMB/LINA(1450),LINB(1450),G(1450),B(1450),P(250),Q(250),
     1LPHB(50),PHANG(50),LTRA(250),LTRB(250),TAP(250),TMN(250),V(250),
     2TMX(250),IUBPP(250),ANG(250),IBUS(250),DBP(250),UBP(3000),
     3BUSNAME(250),LPHA(50),LIST(250),IUBP(250),QMIN(250),QMAX(250),
     4DBPP(250),UBPP(3000),JBP(3000),JBPP(3000),ICC(250),DLP(250),
     5ZOI(1450),ZOR(1450),BDTA(250),CONEC(250),DLQ(250),IPHASE(250)
      COMMON/COMC/ NA(250),NB(250),JCOL(1000),DJ(1000),IDB(250)
      COMMON /CONST/ NBUS,NL,ISS,IPV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC
     1,ITR1,ITR2,PTOL,QTOL,NLC
 1000 FORMAT(T16,"**** BUS NO. ",I3," EXCEEDED ITS MAXIMUM Q LIMIT:"/
     1T21,"Q SPECIFIED:",F8.4," PER-UNIT."/T21,"Q CALCULATED:",
     2F8.4," PER-UNIT."/T21,"AMOUNT EXCEEDED:",F5.2," PERCENT."/)
 1001 FORMAT(T16,"**** BUS NO. ",I3," EXCEEDED ITS MINIMUM Q LIMIT:"/
     1T21,"Q SPECIFIED:",F8.4," PER-UNIT."/T21,"Q CALCULATED:",
     2F8.4," PER-UNIT."/T21,"AMOUNT EXCEEDED:",F5.2," PERCENT."/)
C  THIS SUBROUTINE DETERMINES IF ANY PV TYPE BUSES HAVE EXCEEDED
C  THEIR Q LIMITS.  THE BUS LIST IS SCANNED FOR ALL TYPE 2 BUSSES,
C  AND THE Q CALCULATED FOR EACH.  THE CALCULATED Q IS COMPARED TO
C  THE SPECIFIED Q.  IF THE CALC. Q EXCEEDS THE LIMIT, A CHECK IS
C  THEN MADE TO SEE IF ANY TCUL BRANCHES ARE CONNECTED TO THE BUS.
C  IF YES, THE TAP IS ADJUSTED (WITHIN TAP LIMITS) TO TRY TO HOLD
C  THE SPECIFIED BUS VOLTAGE.  IF NO TCUL'S ARE AVAILABLE, OR THE
C  TAP LIMITS HAVE BEEN REACHED, THE BUS VOLTAGE IS THEN ADJUSTED.
      DO 100 I=1,NBUS
      IF(IDB(I).NE.2) GO TO 100
      II=JADD(I)+IZ
      IF=II+CONEC(I)-1
      BS=BSUM=0.
            DO 10 J=II,IF
            T=TAPR(I,LINB(J))
            BS=BS+T*B(J)
            IF(LINB(J).EQ.0) GO TO 10
            THETA=ANG(I)-ANG(LINB(J))
            BSUM=BSUM+V(LINB(J))*(-G(J)*SIN(THETA)+B(J)*COS(THETA))
   10       CONTINUE
      Q(I)=V(I)*(BSUM-V(I)*BS)
      IF(QMAX(I).EQ.0..AND.QMIN(I).EQ.0.) GO TO 100
      IF(QMAX(I)-Q(I)) 20,100,11
   11 IF(QMIN(I)-Q(I)) 100,100,25
   20 DEL=QMAX(I)-Q(I)
            DO 21 L=1,LOOOP
            IF(LIST(L).EQ.I) GO TO 50
   21       CONTINUE
      LOOOP=LOOOP+1
      EX=(-DEL/QMAX(I))*100.
      WRITE(2,1000) I,QMAX(I),Q(I),EX
      LIST(LOOOP)=I
      GO TO 50
   25 DEL=QMIN(I)-Q(I)
            DO 26 L=1,LOOOP
            IF(LIST(L).EQ.I) GO TO 50
   26       CONTINUE
```

```
      LOOOP=LOOOP+1
      LIST(LOOOP)=I
      IF(QMIN(I).EQ.0.) GO TO 27
      EX=ABS(100.*DEL/QMIN(I))
      GO TO 28
   27 EX=100.*DEL
   28 WRITE(2,1001) I,QMIN(I),Q(I),EX
   50 IF(ABS(DEL).LE..01) GO TO 100
      IF(SK(I).NE.0.) GO TO 90
      K1=JADD(I)+IZ
      K2=K1+CONEC(I)-1
      K=0
      DO 60 L=1,NBUS
      IRW=NB(L)
      IF(IDB(IRW).NE.1) GO TO 60
      K=K+1
           DO 51 J=K1,K2
           IF(IRW.EQ.LINB(J)) GO TO 52
   51        CONTINUE
      DU(K)=0.
      GO TO 60
   52 DU(K)=B(J)
   60 CONTINUE
      BS=0.
      DO 61 L=K1,K2
      T=TAPR(I,LINB(L))
   61 BS=BS-T*B(L)
      IS=K-1
      DO 70 N=1,IS
      K1=IUBPP(N)
      K2=IUBPP(N+1)-1
      IF(K2.LT.K1) GO TO 70
           DO 65 J=K1,K2
           IF(JBPP(J).EQ.0) GO TO 65
           JJ=IPOSI(JBPP(J))
            DU(JJ)=DU(JJ)+UBPP(J)*DU(N)
   65      CONTINUE
   70 CONTINUE
      DO 75 N=1,K
      DU(N)=DBPP(N)*DU(N)
   75 CONTINUE
      TEMP=0.
      DO 80 N=1,K
   80 TEMP=TEMP+DU(N)*DU(N)/DBPP(N)
      SK(I)=1./(BS-TEMP)
   90 DV=SK(I)*DEL/V(I)
      DO 91 L=1,NOTR
      IF(LTRA(L).NE.I) GO TO 91
      IF(ICC(L).GT.69.AND.ICC(L).LT.90) GO TO 92
   91 CONTINUE
C  FALLING OUT THE BOTTOM OF THE LOOP MEANS THAT BUS I DOES NOT HAVE
C  AN LTC BRANCH CONNECTED WITH THE TAPPING END AT BUS I.  THEREFORE
C  CALCULATE ADJUSTED VOLTAGE FOR BUS I.
      V(I)=V(I)+DV
      GO TO 100
   92 TNEW=TAP(L)+DV
      IF(TMX(L)-TNEW) 94,96,93

   93 IF(TMN(L)-TNEW) 96,96,95
   94 TAP(L)=TMX(L)
      V(I)=V(I)+DV
      GO TO 100
   95 TAP(L)=TMN(L)
      V(I)=V(I)+DV
      GO TO 100
C  FUNCTION DISCRET CALC. THE NEAREST PHYSICAL (DISCRETE) TAP SETTING
C  TO TNEW.  THIS VALUE IS STORED AS THE NEW TAP SETTING FOR THE TRANS.
   96 TAP(L)=DISCRET(TNEW)
  100 CONTINUE
      RETURN
      END
```

```
      FUNCTION IPOS(IT)
      COMMON/COMC/ NA(250),NB(250),JCO.(1000),DJ(1000),IDB(250)
      COMMON/CONST/ NBUS,NL,ISS,IPV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC
     1,ITR1,ITR2,PTOL,QTOL,NLC
      K=0
      DO 10 I=1,NBUS
      IF(IDB(NB(I)).EQ.3) GO TO 10
      K=K+1
      IF(NB(I).EQ.IT) GO TO 11
   10 CONTINUE
   11 IPOS=K
      RETURN
      END

      FUNCTION IPOSI(IT)
      COMMON/COMC/ NA(250),NB(250),JCO.(1000),DJ(1000),IDB(250)
      COMMON/CONST/ NBUS,NL,ISS,IPV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC
     1,ITR1,ITR2,PTOL,QTOL,NLC
      K=0
      DO 10 I=1,NBUS
      IF(IDB(NB(I)).NE.1) GO TO 10
      K=K+1
      IF(NB(I).EQ.IT) GO TO 11
   10 CONTINUE
   11 IPOSI=K
      RETURN
      END
      FUNCTION TAPR(ITA,ITB)
C     THIS FUNCTION DETERMINES IF THE BRANCH DEFINED BY ITA AND ITB IS
C     A TRANSFORMER BRANCH.  IF SO, THE PROPER TAP RATIO IS ASSIGNED TO
C     TAPR AND RETURNED TO THE PROGRAM.
      COMMON /COMB/LINA(1450),LINB(1450),G(1450),B(1450),P(250),Q(250),
     1LPHB(50),PHANG(50),LTRA(250),LTRB(250),TAP(250),THN(250),V(250),
     2TMX(250),IUBPP(250),ANG(250),IBUS(250),DBP(250),UBP(3000),
     3BUSNAME(250),LPHA(50),LIST(250),IUBP(250),QMIN(250),QMAX(250),
     4DBPP(250),UBPP(3000),JBP(3000),JBPP(3000),ICC(250),DLP(250),
     5ZBI(1450),ZBR(1450),BDIA(250),CONEC(250),DLQ(250),IPHASE(250)
      COMMON /CONST/ NBUS,NL,ISS,IPV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC
     1,ITR1,ITR2,PTOL,QTOL,NLC
      TAPR=0.
      IF(ITB.EQ.0) GO TO 25
      DO 20 I=1,NOTR
      IF(LTRA(I).NE.ITA) GO TO 10
      IF(LTRB(I).EQ.ITB) TAPR=TAP(I)
      GO TO 20
   10 IF(LTRB(I).NE.ITA) GO TO 20
      IF(LTRA(I).EQ.ITB) TAPR=1./TAP(I)
   20 CONTINUE
   25 IF(TAPR.EQ.0.) TAPR=1.0
      RETURN
      END

      FUNCTION DISCRET(TT)
      I1=1
      X=TT/.00625-160.
      J=X
      IF(ABS(X-J).GE..5) GO TO 5
      DISCRET=1.0+.00625*J
      RETURN
    5 IF(J.LT.0) I1=-1
      J=J+I1
      DISCRET=1.0+.00625*J
      RETURN
      END
```

```
      OVERLAY (SHRTCKT,3,0)                                             023750
      PROGRAM FAULT                                                     023760
C  PROGRAM FAULT IS THE SHORT-CIRCUIT ANALYSIS SEGMENT OF THE OVERALL   023770
C  SYSTEM ANALYSIS PROGRAM.  THIS PROGRAM UTILIZES LARGE MATRIX TECH-   023780
C  NIQUES AND ZBUS MATRIX SYMMETRY TO REDUCE PROGRAM STORAGE REQUIRE-   023790
C  MENTS.  ANY NETWORK UP TO 250 BUSSES CAN BE USED AND THE PROGRAM     023800
C  WILL COMPLETE THE FAULT STUDY BY TAKING 50-BUS "SUBSYSTEMS" OF THE   023810
C  NETWORK AND REDUCING THE REMAINING SYSTEM TO A MESH EQUIVALENT.      023820
C  BY TAKING CONSECUTIVE 50-BUS SEGMENTS, THE ENTIRE NETWORK CAN BE     023830
C  STUDIED IN FIVE PASSES.                                              023840
C  THE PROGRAM USES THE METHOD OF SYMMETRICAL COMPONENTS, AND THE       023850
C  POSITIVE AND ZERO SEQUENCE IMPEDANCE MATRICES ARE STORED AS ONE-     023860
C  DIMENSIONAL ARRAYS, I.E. THE DIAGONAL ELEMENTS OF EACH ARE STORED    023870
C  IN ZDIA AND ZODIA, AND THE UPPER TRIANGLES FOR EACH ARE STORED IN    023880
C  ZBUS AND ZOBUS.                                                      023890
      INTEGER CON,CHG,SCOP,OUT,CONEC,P4,A,C,AA,CC,A1,C1,A2,C2,A3,C3,D,D1023900
      COMPLEX ZZ,OFFDIAG,DIAG,CPLXV,VB,FA3,FA1,ZF,ZDIA,ZODIA,ZBUS,ZOBUS,023910
     1ZM,EBUS,AMPA,ED,ZZE,ZC,ZCOUP,YCOUP,ZZ0,ZG,ZZG(250),FI,FIG,PNS,ZS, 023920
     2FI4                                                               023930
      DIMENSION IFB(25),L1(51),L2(51),CU(51),CUR(51)                    023940
      COMMON /COMA/CON,CHG,LOOOP,SCOP,INP,OUT,F,T,BKVA,RHO1,NMAX,MAXTR, 023950
     1MAXLTC,MAXPH,ISYS,BKVA1                                           023960
      COMMON /COMB/LINA(1450),LINB(1450),G(1450),B(1450),P(250),Q(250), 023970
     1LPHB(50),PHANG(50),LTRA(250),LTRB(250),TAP(250),TMN(250),V(250),  023980
     2TMX(250),IUBPP(250),ANG(250),IBUS(250),OBP(250),UBP(3000),        023990
     3BUSNAME(250),LPHA(50),LIST(250),IUBP(250),QMIN(250),QMAX(250),    024000
     4OBPP(250),UBPP(3000),JBP(3000),JBPP(3000),ICC(250),QLP(250),      024010
     5ZOI(1450),ZOR(1450),BDIA(250),CONEC(250),DLQ(250),IPHASE(250)     024020
      COMMON/COMC/ NA(250),NB(250),JCOL(1000),DJ(1000),IDB(250)         024030
      COMMON /CONST/ NBUS,NL,ISS,IPV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC      024040
     1,ITR1,ITR2,PTOL,QTOL,NLC                                          024050
      COMMON /SAVE/ IERR                                                024060
      COMMON /ZERO/LA(25),LB(25),LR(25),LS(25),ZM(25),YCOUP(8,8),       024070
     1ZCOUP(25),IJK(25),KJI(25),ITZ(25),ISAVE(8),ZDIA(75),ZODIA(75),    024080
     2ZBUS(2775),ZOBUS(2775),EBUS(250),ZC(75)                           024090
      COMMON /ZCONST/ NOMU,NBS,IROW,INUT,IDUMM                          024100
 1000 FORMAT(1X,"NUMBER OF LINES ADDED BY 'FAULT' TRANSFORMER ROU-      024110
     1TINE HAS"/1X,"EXCEEDED MAXIMUM LINE TABLE STORAGE CAPACITY!"/     024120
     21X,"LINE NO.",I4," OF TRANSFORMER TABLE."/)                       024130
 1001 FORMAT(1X,"NUMBER OF LINES ADDED BY 'FAULT' SOURCE IMPEDANCE ROU- 024140
     1TINE HAS"/1X,"EXCEEDED MAXIMUM STORAGE CAPACITY OF LINE TABLES!"/ 024150
     21X,"CARD NO.",I4," OF SOURCE IMPEDANCE DATA."/)                   024160
 1002 FORMAT(1X,"ERROR IN FEASIBLE BUS LIST ROUTINE!"/1X,"NO. OF BUSSES 024170
     1IN SYSTEM=",I4/1X,"FEASIBLE BUS LIST"/(14I5))                     024180
 1003 FORMAT(1X,"NO. OF MUTUAL LINES DECLARED=",I4,"!"/1X,              024190
     1"MAXIMUM ALLOWED=25!"/)                                           024200
 1004 FORMAT(1X,"NO. OF BUSSES IN SYSTEM AREA=",I4,"!"/1X,              024210
     1"MAXIMUM ALLOWED=50!"/)                                           024220
 1005 FORMAT(1X,"ERROR IN TRANSFORMER CONNECTION CODE!  TXFR NO.",I4/   024230
     11X,"SEE INPUT LINE LIST. WRONG CODE=",I4,". CODE IS C+IADD."/)    024240
 1006 FORMAT(1X,"ERROR BETWEEN TRANSFORMER AND LINE TABLES!"/1X,        024250
     1"COULDN'T FIND TRANS. BRANCH (SB=",I4," AND EB=",I4,") CONNECTED  024260
     2TO BUS",I4," IN LINE TABLES."/)                                   024270
 1007 FORMAT(1X,"'FAULT' SOURCE IMPEDANCE ROUTINE HAS DETECTED A ZERO   024280
     1INPUT FOR"/1X,"THREE-PH. FAULT CURRENT.  THREE-PH. FAULT CURRENT  024290
     2MUST BE NON-ZERO!"/1X,"SOURCE IMPEDANCE CARD NO.",I4/)            024300
 1008 FORMAT(1X,"ERROR IN LINE TABLE!  FIRST ENTRY IN LINA SHOULD BE    024310
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      1THE REF BUS(=0)."/1X,"ACTUAL TABLE ENTRY=",I4/)                  024320
 1009 FORMAT(26I3)                                                      024330
 1010 FORMAT(1H1/T23,29(1H*)/T23,1H*,T25,"FAULT SUMMARY FOR BUS",I4,1X  024340
     1,1H*/T23,1H*,T27,"ZF= (",F5.2,",",F5.2,") P.U.",T51,1H*/T23,1H*   024350
     2,T27,"ZG= (",F5.2,",",F5.2,") P.U.",T51,1H*/T23,29(1H*)/)         024360
 1011 FORMAT(T4,"THREE-PHASE",T23,"PHASE-GROUND",T42,"PHASE-PHASE",T60, 024370
     1"PH-PH-GROUND"/T2,16(1H*),3X,16(1H*),3X,16(1H*),2X,16(1H*)/T2,    024380
     2"IF(MAG)=",F8.4,T21,"IF(MAG)=",F9.4,T40"IF(MAG)=",F8.4,T58,       024390
     3"IF(MAG)=",F8.4/T2,"X/R=",F9.3,T21,"X/R=",F8.3,T40,"X/R=",F8.3,   024400
     4T59,"X/R=",F8.3/T2,16(1H*),3X,15(1H*),T40,"EF(A)=",F7.4,T58,      024410
     5"EF(A)=",F7.4/T40,"EF(B)=",F7.4,T58,"EF(B)=",F7.4/T40,"EF(C)=",   024420
     6F7.4,T59,"EF(C)=",F7.4/T40,16(1H*),T58,"IF(B)=",F7.4/T59,         024430
     7"X/R(B)=",F8.3/T58,"IF(C)=",F8.4/T59,"X/R(C)=",F8.3/T58,16(1H*))  024440
 1012 FORMAT(T4,"BUS VOLTAGES",T22,"PHASE VOLTAGES"/T2,"BUS",T9,        024450
     1"V(MAG)",T24,"A",T29,"B",T34,"C"/(1X,I3,3X,F9.4,5X,F4.2,1X,       024460
     2F4.2,1X,F4.2))                                                    024470
 1013 FORMAT(T22,"THREE-PHASE",T41,"PHASE-GROUND"/T20,16(1H*),3X,15(1H*)024480
     1/T20,"IF(MAG)=",F8.4,T39,"IF(MAG)=",F8.4/T20,"X/R=",F8.3,T39,     024490
     2"X/R=",F8.3/T20,16(1H*),3X,15(1H*))                               024500
 1014 FORMAT(//T22,"BUS VOLTAGES",T40,"PHASE VOLTAGES"/T20,"BUS",T27,   024510
     1"V(MAG)",T42,"A",T47,"B",T52,"C"/                                 024520
     2(19X,I3,3X,F9.4,5X,F4.2,1X,F4.2,1X,F4.2))                         024530
 1015 FORMAT(I3,2X,6F9.2,4F5.1)                                         024540
 1016 FORMAT(4I3,3X,2F10.5)                                             024550
 1017 FORMAT(1X,"ERROR IN FEASIBLE BUS LIST ROUTINE!"/1X,"LINE LIST DOES024560
     1 NOT INCLUDE ALL LINES IN SYSTEM."/1X,"NO. OF LINES IN SYSTEM=",  024570
     2I5/1X,"NO. OF LINES IN LIST=",I5/1X,"FEASIBLE LINE LIST"/(14I5))  024580
 1018 FORMAT(//1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,T20,                    024590
     1"RESULTS OF SHORT CIRCUIT ANALYSIS",T71,1H*/1X,1H*,T25,           024600
     2"ALL VALUES ARE PER-UNIT",T71,1H*/1X,1H*,T14,                     024610
     3"SYSTEM HAS",I4," BUSES. FAULT CODE(SCOP) IS",I3," .",T71,        024620
     41H*/1X,1H*,T18,"THERE ARE",I4," SUBSYSTEM STUDIES(ISYS).",        024630
     5T71,1H*/1X,1H*,68X,1H*/1X,70(1H*)//)                              024640
 1019 FORMAT(1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,T25,"SUBSYSTEM STUDY NO.",024650
     1I4," ",T71,1H*/1X,1H*,T19,"NUMBER OF BUSSES IN THIS SYSTEM IS:",  024660
     2I3,".",T71,1H*/1X,1H*,68X,1H*/1X,70(1H*)//)                       024670
 1020 FORMAT(1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,T22,"AUTOMATIC SHORT-CIRCU024680
     1IT STUDY:",T71,1H*/1X,1H*,T15,"ENTIRE NETWORK STUDY WILL BE COMPLE024690
     2TED",T71,1H*/1X,1H*,T15,"IN",I2," PASSES OF SHORT-CIRCUIT PROGRAM.024700
     3",T71,1H*/1X,1H*,68X,1H*/1X,70(1H*)//)                            024710
 1021 FORMAT(T31,"PHASE-GROUND"/T29,15(1H*)/T29,"IF(MAG)=",F7.4/T29,    024720
     1"X/R=",F8.3/T29,16(1H*))                                          024730
 1022 FORMAT(//T27,"BUS",T33,"PHASE VOLTAGES"/T35,"A",T40,"B",T45,"C"/  024740
     1(25X,I3,3X,F4.2,1X,F4.2,1X,F4.2))                                 024750
 1030 FORMAT(T15,I3,1X,I3,1X,F8.4,9X,F9.4)                              024760
 1031 FORMAT(//T4,"LINE CURRENTS",T22,"LINE CURRENTS")                  024770
 1032 FORMAT(T2,"LINE",5X,"FAULT(I)",T22,"FAULT(I) PH-A")               024780
 1033 FORMAT(1X,I3,1X,I3,1X,F8.4,9X,F9.4)                               024790
 1036 FORMAT(/1X,70(1H*)/1X,1H*,68X,1H*/1X,1H*,T25,"SHORT CIRCUIT INPUT 024800
     1DATA",T71,1H*/1X,1H*,68X,1H*/1X,70(1H*)//)                        024810
 1037 FORMAT(1X,"SOURCE IMPEDANCE BUS NO.",I3,5X,"VOLTS L-N(KV)",2F9.2/ 024820
     11X,"3-PH FAULT CURRENT(AMPS)",2F9.2/1X,"PH-GND FAULT CURRENT(AMPS 024830
     2)",2F9.2/1X,"FAULT Z(OHMS)",2F5.1,"!  NEUT Z(OHMS)",2F5.1//)      024840
 1038 FORMAT(1X,"Z0R AND Z0I OF LINE",I4," TO",I4," SHOULDN'T BE ZERO.")024850
 1039 FORMAT(1X,"Z0IA OF BUS",I4," SHOULD NOT BE ZERO.")                024860
 1040 FORMAT(//T31,"LINE CURRENTS"/T29,"LINE",T38,"FAULT(I)")           024870
 1041 FORMAT(T27,I3,1X,I3,4X,F7.4)                                      024880
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1042 FORMAT(1X,"MUTUAL COUPLING DATA"/1X,"LA=",I3,"LB=",
    1I3,"LR=",I3,"LS=",I3/1X,"MUTUAL IMPEDANCE (OHMS)=",2F10.5/)
1043 FORMAT(/1X,"FAULT IMPEDANCE(ZF)(OHMS)=",2(F6.3,1X)/1X
    1,"PHASE=",I2,1X,"BUS VOLTAGE(KV)=",F6.2)
1044 FORMAT(R6,I3,2F6.0,I3,F6.0)
1045 FORMAT(1X,"BUS",I3)
1046 FORMAT(/T22,"LINE CURRENTS",T41,"LINE CURRENTS"/T20,"LINE",
    25X,"FAULT(I)",T42,"FAULT(I) PH-A")
1047 FORMAT(R6,2I3)
1048 FORMAT(T3,"PROGRAM CONTROL CARD NOT IN PROPER FORMAT OR LOCATION.
    1CARD WITH KEYWORD ",R6," IS REQUIRED."/)
1049 FORMAT(T3,"BUS 0 CAN NOT BE IN SUBSYSTEM LIST.DOES NBS NUMBER
    1EQUAL NUMBER OF BUSES LISTED ON SUBSYSTEM CARD?")
1050 FORMAT("PM PLEASE USE LU06...")
1051 FORMAT(I2,I3,A10,2F5.0,4F10.0)
1052 FORMAT(R6,I3)
     READ(5,1047) A,ISYS,SCOP
     IF(OUT.EQ.11.OR.OUT.EQ.14) WRITE(2,1050)
     C=$RSHTCKT
     IF(A.EQ.C) GO TO 5
     D=$RLDFLOW
     IF(A.NE.D) GO TO 912
     DO 2 I=1,NBUS
     READ(5,1051) IDB(I),IBUS(I),BUSNAME(I),V(I),ANG(I),P(I),Q(I),
    1QMIN(I),QMAX(I)
   2 CONTINUE
     READ(5,1047) A,ISYS,SCOP
     D1=$RBUSCHG
   4 IF(A.EQ.C) GO TO 5
     IF(A.NE.D1) GO TO 912
     READ(5,1051) (IDB(I),IBUS(I),BUSNAME(I),V(I),ANG(I),P(I),Q(I),
    1QMIN(I),QMAX(I),I=1,ISYS)
     READ(5,1047) A,ISYS,SCOP
     GO TO 4
C  THE FOLLOWING SECTION PROCESSES TRANSFORMER DATA TO ADD LINES
C  REFERENCE IF REQUIRED IN THE ZERO SEQUENCE.
   5 IF(OUT.EQ.2.OR.OUT.EQ.10) GO TO 6
     WRITE(1,1036)
   6 MAXLIN=1450
     IZADD=0
     DO 7 I=1,NBUS
     MA(I)=CONEC(I)
     DLP(I)=DLQ(I)=0.
   7 CONTINUE
     IF(NOTR.EQ.0) GO TO 51
     DO 50 I=1,NOTR
     IF(ICC(I).LT.41) GO TO 905
     IF(ICC(I).LT.61) GO TO 9
     IF(ICC(I).LT.71) GO TO 10
     IF(ICC(I).LT.91) GO TO 15
     IF(ICC(I).GT.100) GO TO 905
C  FALL THROUGH: TRANSFORMER IS PHASE SHIFTER TYPE:
     IF(ICC(I).EQ.91.OR.ICC(I).EQ.94.OR.ICC(I).GT.96) 50,20
C  TRANSFORMER IS TYPE FIXED:
   9 IF(ICC(I).LT.44.OR.ICC(I).EQ.46.OR.ICC(I).GT.48) GO TO 34
     IF(ICC(I).EQ.44) GO TO 30
     IF(ICC(I).EQ.45.OR.ICC(I).EQ.48) GO TO 25
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      GO TO 905
C   TRANSFORMER IS TYPE AUTO:
   10 IF(ICC(I).LT.63.OR.ICC(I).EQ.64.OR.ICC(I).EQ.67) GO TO 40
      IF(ICC(I).EQ.63.OR.ICC(I).EQ.65.OR.ICC(I).EQ.66) GO TO 20
      IF(ICC(I).EQ.68) GO TO 25
      GO TO 905
C   TRANSFORMER IS TYPE TCUL:
   15 IF(ICC(I).LT.74.OR.ICC(I).EQ.75.OR.ICC(I).GT.78) GO TO 50
      IF(ICC(I).EQ.77) GO TO 20
      IF(ICC(I).EQ.75.OR.ICC(I).EQ.78) GO TO 25
      IF(ICC(I).EQ.74) GO TO 30
      GO TO 905
C   ADD LINE FROM P TO REF: ADD LINE FROM Q TO REF:
   20 K1=JADD(LTRA(I))+IZ
      K2=K1+NA(LTRA(I))-1
           DO 21 J=K1,K2
           IF(LINB(J).EQ.LTRA(I)) GO TO 22
   21        CONTINUE
      GO TO 906
   22 NL=NL+2
      IF(NL.GT.MAXLIN) GO TO 900
      LINA(NL)=0
      LINB(NL)=LTRA(I)
      LINA(NL-1)=LTRA(I)
      LINB(NL-1)=0
      Z0R(NL)=.8*Z0R(J)
      Z0I(NL)=.8*Z0I(J)+.1
      Z0R(NL-1)=Z0R(NL)
      Z0I(NL-1)=Z0I(NL)
      CONEC(LINA(J))=CONEC(LINA(J))+1
      IZADD=IZADD+1
      NL=NL+2
      IF(NL.GT.MAXLIN) GO TO 900
      LINA(NL)=0
      LINB(NL)=LTRB(I)
      LINA(NL-1)=LTRB(I)
      LINB(NL-1)=0
      Z0R(NL)=2.*Z0R(J)
      Z0I(NL)=2.*Z0I(J)
      Z0R(NL-1)=Z0R(NL)
      Z0I(NL-1)=Z0I(NL)
      CONEC(LINB(J))=CONEC(LINB(J))+1
      IZADD=IZADD+1
      GO TO 50
C   ADD LINE FROM Q TO REF: Q=EB
   25 K1=JADD(LTRA(I))+IZ
      K2=K1+NA(LTRA(I))-1
           DO 26 J=K1,K2
           IF(LINB(J).EQ.LTRB(I)) GO TO 27
   26        CONTINUE
      GO TO 906
   27 NL=NL+2
      IF(NL.GT.MAXLIN) GO TO 900
      LINA(NL)=0
      LINB(NL)=LTRB(I)
      LINA(NL-1)=LTRB(I)
      LINB(NL-1)=0
```

```
      ZOR(NL)=ZOR(J)
      ZOI(NL)=ZOI(J)
      ZOR(NL-1)=ZOR(NL)
      ZOI(NL-1)=ZOI(NL)
      CONES(LINB(J))=CONES(LINB(J))+1
      IZADD=IZADD+1
      GO TO 40
C   ADD LINE FROM P TO REF1
   30 K1=JADD(LTRA(I))+IZ
      K2=K1+NA(LTRA(I))-1
          DO 31 J=K1,K2
          IF(LINB(J).EQ.LTRB(I)) GO TO 32
   31     CONTINUE
      GO TO 906
   32 NL=NL+2
      IF(NL.GT.MAXLIN) GO TO 900
      LINA(NL)=0
      LINB(NL)=LTRA(I)
      LINA(NL-1)=LTRA(I)
      LINB(NL-1)=0
      ZOR(NL)=ZOR(J)
      ZOI(NL)=ZOI(J)
      ZOR(NL-1)=ZOR(NL)
      ZOI(NL-1)=ZOI(NL)
      CONES(LINA(J))=CONES(LINA(J))+1
      IZADD=IZADD+1
      GO TO 40
   34 IF(ICC(I).LT.43) 35,40
   35 K1=JADD(LTRA(I))+IZ
      K2=K1+NA(LTRA(I))-1
        DO 36 J=K1,K2
        IF(LINB(J).EQ.LTRB(I)) GO TO 37
   36   CONTINUE
      GO TO 906
   37 ZOR(J)=1.E10
      ZOI(J)=0.
      K1=JADD(LTRB(I))+IZ
      K2=K1+NA(LTRB(I))-1
        DO 38 J=K1,K2
        IF(LINB(J).EQ.LTRA(I)) GO TO 39
   38   CONTINUE
      GO TO 906
   39 ZOR(J)=1.E10
      ZOI(J)=0.
      GO TO 50
   40 IF(ICC(I).EQ.44.OR.ICC(I).EQ.45.OR.(ICC(I).GT.47
     1.AND.ICC(I).LT.51).OR.ICC(I).EQ.51.OR.ICC(I).EQ.68.OR.ICC(I).EQ.71
     2.OR.ICC(I).EQ.72.OR.ICC(I).EQ.74.OR.ICC(I).EQ.75.OR.(ICC(I).GT.
     377.AND.ICC(I).LT.81)) 41,50
C   LTRA=SB,LTRB=EB
   41 LBUS=LTRA(I)
      IF(LTRB(I).GT.LTRA(I)) LBUS=LTRB(I)
      LLBUS=LTRB(I)
      IF(LTRB(I).GT.LTRA(I)) LLBUS=LTRA(I)
      K1=JADD(LBUS)+IZ
      K2=K1+NA(LBUS)-1
          DO 42 J=K1,K2
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      IF(LINB(J).EQ.LLBUS) GO TO 43
42    CONTINUE
      GO TO 906
   43 ZOR(J)=1.E10
      ZOI(J)=0.
   50 CONTINUE
C     THE FOLLOWING SECTION PROCESSES GENERATOR BUSSES TO ADD SOURCE
C     IMPEDANCES.  THIS INCLUDES THE SLACK BUS.  THE SOURCE IMPEDANCES
C     ARE CALCULATED FROM THE THREE-PHASE AND SINGLE-PHASE TO GROUND
C     FAULTS FOR EACH BUS, WHICH ARE READ IN BY THE FOLLOWING ROUTINE.
C     THIS ROUTINE MAY BE BYPASSED IF THE SOURCE IMPEDANCES ARE TO BE
C     IGNORED, AND THERE IS AT LEAST ONE LINE TO REFERENCE IN THE LINE
C     TABLE.  THE ROUTINE IS BYPASSED IF IREF=0.
   51 READ(5,1052) AA,IREF
      CC=6RCURSOR
      IF(AA.NE.CC) GO TO 914
      IF(IREF.EQ.0) GO TO 65
      DO 60 I=1,IREF
      READ(5,1015) IBF,VB,FA3,FA1,ZF,ZG
      IF(OUT.EQ.2.OR.OUT.EQ.10) GO TO 52
      WRITE(1,1037) IBF,VB,FA3,FA1,ZF,ZG
   52 VP=CABS(VB)
      ZB=3000.*VP*VP/BKVA
      Z1=CABS(FA3)
      IF(Z1.EQ.0.) GO TO 907
      IF(ZB.EQ.0) GO TO 907
      ZZ=VB*1000./FA3-ZF
      Z1=CABS(FA1)
      IF(Z1.EQ.0.) GO TO 55
      ZZ0=(3000.*VB/FA1-2.*ZZ-3.*ZF)/ZB
      ZZ=ZZ/ZB
      GO TO 56
   55 ZZ0=CMPLX(1.E10,0.)
      ZZ=ZZ/ZB
   56 NL=NL+2
      IF(NL.GT.MAXLIN) GO TO 901
      LINA(NL)=0
      LINB(NL)=IBF
      LINA(NL-1)=IBF
      LINB(NL-1)=0
      G(NL)=REAL(1./ZZ)
      B(NL)=AIMAG(1./ZZ)
      G(NL-1)=G(NL)
      B(NL-1)=B(NL)
      ZOR(NL)=REAL(ZZ0)
      ZOI(NL)=AIMAG(ZZ0)
      ZOR(NL-1)=ZOR(NL)
      ZOI(NL-1)=ZOI(NL)
      ZZG(IBF)=ZG/ZB
      IZADD=IZADD+1
      CONEC(IBF)=CONEC(IBF)+1
   60 CONTINUE
      IF(IERR.NE.0) RETURN
C     ADDED LINES ARE NOW COMPLETE; RESORT LINE TABLES INTO ASCENDING
C     BUS ORDER;
   65 CALL LSORT(2,LINA,LINB,NL,4,3,0,ZOR,ZOI,0)
      IZ=IZ+IZADD
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      DO 65 I=1,NBUS
      NA(I)=CONEC(I)
   66 CONTINUE
C  THE FOLLOWING SECTION FORMS A FEASIBLE ORDERING OF THE BUS LISTS
C  FOR THE BUS IMPEDANCE BUILDING ALGORITHM.
      IK=1
      IF(LINA(1).NE.0) GO TO 908
      LIST(1)=LINB(1)
      K=2
      DO 75 I=1,NBUS
      IRW=LIST(I)
      K1=JADD(IRW)+IZ
      K2=K1+CONEC(IRW)-1
         DO 75 J=K1,K2
         IF(LINB(J).EQ.0) GO TO 74
         KK=K-1
            DO 71 M=1,KK
            IF(LIST(M).EQ.LINB(J)) GO TO 73
   71       CONTINUE
         LIST(K)=LINB(J)
         K=K+1
   73    IF(LINA(J).GT.LINA(J)) GO TO 75
   74    JBP(IK)=J
         IK=IK+1
   75    CONTINUE
   76 CONTINUE
      IF(K.NE.(NBUS+1)) GO TO 902
      ISS=NL/2
      IF(IK.NE.(ISS+1)) GO TO 909
C  AFTER THE LINES ARE REORDERED INTO A FEASIBLE LIST, THE MUTUAL
C  COUPLING DATA IS READ IN.  THIS INCLUDES THE MUTUALS FOR ALL LINES
C  IN THE SYSTEM, REGARDLESS OF HOW THE SHORT-CIRCUIT STUDY IS TO PRO-
C  CEED (I.E. BY SUBSYSTEM AREAS OR COMPLETE SYSTEM).  A MAXIMUM OF
C  25 MUTUALLY COUPLED LINES ARE ALLOWED FOR IN THE PROGRAM.
      READ(5,1052) A1,NOMU
      C1=6RNOMUTL
      IF(A1.NE.C1) GO TO 915
      IF(NOMU.EQ.0) GO TO 77
      IF(NOMU.GT.25) GO TO 903
      READ(5,1016) (LA(I),LB(I),LR(I),LS(I),ZM(I),I=1,NOMU)
      IF(OUT.EQ.2.OR.OUT.EQ.10) GO TO 77
      WRITE(1,1042) (LA(I),LB(I),LR(I),LS(I),ZM(I),I=1,NOMU)
C  THE FOLLOWING SECTION PROCESSES FAULT IMPEDANCE DATA TO BE USED IN
C  THE FAULT CALCULATIONS.  THE FIRST CARD READ IN INDICATES HOW
C  MANY FAULT IMPEDANCES WILL BE ENTERED(NOFALT), THE FAULT IMPEDANCE
C  (OHMS), NO. OF PHASES, AND PHASE-GND VOLTAGE(KV).  SUCCEEDING CARDS
C  READ IN THE LIST OF BUS NUMBERS TO WHICH THIS FAULT DATA APPLIES.
C  A BLANK CARD SIGNALS THE END OF THE FAULT IMPEDANCE DATA. NOFALT=NFT.
   77 READ(5,1044) A2,NOFALT,ZF,PH,VP
      C2=6RNOFALT
      IF(A2.NE.C2) GO TO 916
      IF(NOFALT.EQ.0) GO TO 84
      IF(OUT.EQ.2.OR.OUT.EQ.10) GO TO 80
      WRITE(1,1043) ZF,PH,VP
   80 IF(PH.EQ.1) BKVA=BKVA/3.
      ZB=(1000.*VP*VP)/BKVA
      IF(PH.EQ.1) BKVA=BKVA1
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      KYZ=NOFALT/26.+.99
      INT=KYZ
           DO 83 I=1,INT
           READ(5,1009) IFB
           DO 82 J=1,25
                IF(IFB(J).EQ.0) GO TO 83
                IF(OUT.EQ.2.OR.OUT.EQ.10) GO TO 81
                WRITE(1,1045) IFB(J)
   81           DLP(IFB(J))=REAL(ZF/ZB)
                DLQ(IFB(J))=AIMAG(ZF/ZB)
   82           CONTINUE
   83      CONTINUE
      GO TO 77
C  THE FOLLOWING SECTION BEGINS THE BUS BUILDING ALGORITHM FOR THE
C  POSITIVE AND ZERO SEQUENCE IMPEDANCE MATRICES.  IF SHORT-CIRCUIT
C  IS TO BE PERFORMED ON COMPLETE NETWORK (ISYS=0) SKIP TO 100.
C  OTHERWISE, READ IN AREA BUS LIST(S).  A MAXIMUM OF 50 BUSSES PER
C  AREA IS ALLOWED.  VALUES OF ISYS FROM 1 TO 99 INDICATE HOW MANY
C  AREAS ARE TO BE STUDIED.  FIRST, THE BUS VOLTAGES ARE INITIALIZED:
   84 IF(LODOP.EQ.-1.AND.SCOP.EQ.1) SCOP=0
      IF(LODOP.EQ.-1.AND.SCOP.EQ.3) SCOP=2
      IF(SCOP.EQ.1.OR.SCOP.EQ.3) GO TO 86
      DO 85 I=1,NBUS
   85 EBUS(I)=CMPLX(1.,0.)
      GO TO 90
   86 DO 87 I=1,NBUS
   87 EBUS(I)=CPLXV(V(I),ANG(I))
   90 WRITE(2,1018) NBUS,SCOP,ISYS
      IF(ISYS.EQ.0) GO TO 100
      ICOUNT=ISYS
   95 IF(ICOUNT.EQ.0) RETURN
      IOUT=ISYS-ICOUNT+1
      READ(5,1052) A3,NBS
      B3=6HNOBSYS
      IF(B3.NE.A3) GO TO 917
      IF(NBS.GT.50) GO TO 904
      WRITE(2,1019) IOUT,NBS
      READ(5,1009) (NB(I),I=1,NBS)
      DO 98 I=1,NBS
      IF(NB(I).EQ.0) GO TO 913
   98 CONTINUE
      GO TO 105
  100 DO 101 I=1,NBUS
      NB(I)=LIST(I)
  101 CONTINUE
      KYZ=NBUS/50.+.99
      IOUT=KYZ
      WRITE(2,1020) IOUT
      NBS=50
      IF(NBUS.LT.50) NBS=NBUS
  105 M=0
C  THE POSITIVE SEQ. BUILDING ALGORITHM IS SUBROUTINE BUS.  THE POSI-
C  TIVE SEQ. MATRIX IS STORED AS A VECTOR OF DIAGONAL TERMS (ZDIA),
C  AND AS A VECTOR OF THE UPPER-TRIANGLE TERMS (ZBUS).
  106 CALL BUS(M)
      IF(IERR.NE.0) RETURN
C  THE ZERO SEQ. BUILDING ALGORITHM IS SUBROUTINE BUS0.  THE ZERO
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C  SEQ. MATRIX IS ALSO STORED AS A VECTOR OF DIAGONAL TERMS (Z0DIA),
C  AND A VECTOR OF UPPER TRIANGLE TERMS (Z0BUS).  MUTUAL COUPLING
C  IS HANDLED BY SUBROUTINE MUTEST, WHICH IS CALLED BY BUS0.
      CALL BUS0(M)
      IF(IERR.NE.0) RETURN
C  THE FOLLOWING SECTION CALCULATES THE FAULT CURRENTS.  THE OPTION
C  IS PROVIDED TO CALCULATE ALL FAULT TYPES (3-PH, L-G, L-L, AND
C  L-L-G), OR JUST THE FIRST TWO.
      DO 200 I=1,NBS
      IRW=IUBP(I)
      ZF=CMPLX(DLP(IRW),DLQ(IRW))
      ZG=ZZG(IRW)
      IF(IPHASE(IRW).EQ.1) GO TO 132
C  CALCULATE THE THREE-PHASE FAULT FOR THE ITH BUS:
      ZZ=ZF+ZDIA(I)
      IF(ZZ.EQ.0) GO TO 910
      AMPA=EBUS(IRW)/ZZ
      XR=AIMAG(ZZ)/REAL(ZZ)
      FAULTI=CABS(AMPA)
C  CHECK TO SEE IF BUS VOLTAGE SUMMARY IS TO BE COMPUTED:
      IF(OUT.EQ.12.OR.OUT.EQ.10) GO TO 132
C  COMPUTE VOLTAGE SUMMARIES:
          DO 124 J=1,NBS
          IRW1=IUBP(J)
          IF(J.EQ.I) GO TO 123
          N1=IADD(J,I)
          EC=EBUS(IRW1)-ZBUS(N1)*EBUS(IRW)/ZZ
          DU(J)=CABS(EC)
          GO TO 124
  123     EC=ZF*EBUS(IRW)/ZZ
          DU(J)=CABS(EC)
  124     CONTINUE
C  COMPUTE PHASE-GROUND FAULT FOR ITH BUS:
  132 ZZ=Z0DIA(I)+2.*ZDIA(I)+3.*ZF
      AMPA=3.*EBUS(IRW)/ZZ
      ZZE=ZZ/3.
      XRLG=AIMAG(ZZE)/REAL(ZZE)
      FAULTLG=CABS(AMPA)
C  CHECK TO SEE IF BUS PHASE VOLTAGE SUMMARIES ARE TO BE COMPUTED:
  133 IF(OUT.EQ.12.OR.OUT.EQ.10) GO TO 149
C  CALCULATE PHASE VOLTAGE SUMMARIES:
          DO 135 J=1,NBS
          IRW1=IUBP(J)
          IF(J.EQ.I) GO TO 134
          N1=IADD(J,I)
          EC=EBUS(IRW1)-EBUS(IRW)*(Z0BUS(N1)+2.*ZBUS(N1))/ZZ
          UAP(J)=CABS(EC)
          IF(IPHASE(IRW1).EQ.1) GO TO 135
          EC=EBUS(IRW1)*(-.5,-.866)-EBUS(IRW)*(Z0BUS(N1)-ZBUS(N1))/ZZ
          UBP(NBS+J)=CABS(EC)
          EC=EBUS(IRW1)*(-.5,.866)-EBUS(IRW)*(Z0BUS(N1)-ZBUS(N1))/ZZ
          UBP(2*NBS+J)=CABS(EC)
          GO TO 135
  134     EC=EBUS(IRW)*3.*ZF/ZZ
          UBP(J)=CABS(EC)
          IF(IPHASE(IRW).EQ.1) GO TO 135
          EC=EBUS(IRW)*(-.5,-.866)-EBUS(IRW)*(Z0DIA(I)-ZDIA(I))/ZZ
```

```
              UBP(NBS+J)=CABS(EC)
              EC=EBUS(IRW)*(-.5,.866)-EBUS(IRW)*(ZODIA(I)-ZDIA(I))/ZZ
              UBP(2*NBS+J)=CABS(EC)
  135         CONTINUE
C  COMPUTE LINE FAULT CURRENTS FOR 3-PH,CU(LL), AND LINE-GND.
C  USE Z MATRIX(ZBUS AND ZDIA).  SCAN LINE TABLE FOR LINES CONNECTING
C  BUSSES IN ISYS, THEN CAL. FAULT CURRENT AS CU(LL) AND CUR(LL).
      NBA=NBS
      LL=1
      DO 140 NN=1,51
      L1(NN)=L2(NN)=0
  140 CONTINUE
      DO 148 II=1,NBS
        DO 147 L=1,NL
        IF(LINA(L).NE.IUBP(II)) GO TO 147
        IF(LINA(L).LT.LINB(L)) GO TO 147
          DO 146 JJ=1,NBA
          IF(LINB(L).NE.IUBP(JJ)) GO TO 146
      IF(CMPLX(ZOR(L),ZOI(L)).EQ.0) GO TO 911
        IF(JJ.EQ.I) GO TO 142
          IF(II.EQ.I) GO TO 143
          N1=IADD(II,I)
          N2=IADD(JJ,I)
          FI=ZBUS(N2)-ZBUS(N1)
          PNS=2*(ZBUS(N1)-ZBUS(N2))*CMPLX(G(L),B(L))
          ZS=(ZOBUS(N1)-ZOBUS(N2))/CMPLX(ZOR(L),ZOI(L))
          GO TO 145
  142     N1=IADD(II,I)
          FI=ZDIA(I)-ZBUS(N1)
          GO TO 144
  143     N1=IADD(JJ,I)
          FI=ZBUS(N1)-ZDIA(I)
          GO TO 144
  144     PNS=2*(ZDIA(I)-ZBUS(N1))*CMPLX(G(L),B(L))
          ZS=(ZODIA(I)-ZOBUS(N1))/CMPLX(ZOR(L),ZOI(L))
  145     FIG=(PNS+ZS)/ZZ
          FIA=FI*CMPLX(G(L),B(L))/(ZDIA(I)+ZF)
          CU(LL)=CABS(FIA)
          IF(IPHASE(IRW).EQ.1) CU(LL)=0
          CUR(LL)=CABS(FIG)
          L1(LL)=LINA(L)
          L2(LL)=LINB(L)
          LL=LL+1
  146     CONTINUE
  147   CONTINUE
  148 CONTINUE
C  CHECK TO SEE IF L-L AND L-L-G FAULTS ARE TO BE CALCULATED:
  149 IF(SCOP.EQ.2.OR.SCOP.EQ.3) GO TO 160
      IF(IPHASE(IRW).EQ.1) GO TO 170
C  CALCULATE L-L FAULT FOR ITH BUS(B AND C PHASES FAULTED):
      ZZ=ZF+2.*ZDIA(I)
      IF(ZZ.EQ.0) GO TO 910
      AMPA=1.732*EBUS(IRW)/ZZ
      ZZE=ZZ/1.732
      XRLL=AIMAG(ZZE)/REAL(ZZE)
      FAULTLL=CABS(AMPA)
      EC=EBUS(IRW)*(ZF+2.*ZDIA(I))/ZZ
```

```
      UBP(1001)=CABS(EC)
      EC=EBUS(IRW)*((-.5,-.866)*ZF-ZDIA(I))/ZZ
      UBP(1002)=CABS(EC)
      EC=EBUS(IRW)*((-.5,.866)*ZF-ZDIA(I))/ZZ
      UBP(1003)=CABS(EC)
C   COMPUTE L-L-G FAULT FOR ITH BUS:
      ZZ=ZDIA(I)+2.*(Z0DIA(I)+3.*(ZF+ZG))
      AMPA=3.*EBUS(IRW)/ZZ
      FALTLLG=CABS(AMPA)
      XRLLG=AIMAG(ZZ)/REAL(ZZ)
      ZZ=ZDIA(I)*ZDIA(I)+2.*ZDIA(I)*(Z0DIA(I)+3.*(ZF+ZG))
      AMPA=1.732*EBUS(IRW)*(Z0DIA(I)-(-.5,.866)*ZDIA(I)+3.*(ZF+ZG))/ZZ
      FAULTLB=CABS(AMPA)
      ZZE=ZZ/(1.732*(Z0DIA(I)-(-.5,.866)*ZDIA(I)+3.*(ZF+ZG)))
      XRLB=AIMAG(ZZE)/REAL(ZZE)
      IF(XRLB.LT.0) XRLB=XRLB*(-1.)
      AMPA=1.732*EBUS(IRW)*(Z0DIA(I)-(-.5,-.866)*ZDIA(I)+3.*(ZF+ZG))/ZZ
      FAULTLC=CABS(AMPA)
      ZZE=ZZ/(1.732*(Z0DIA(I)-(-.5,-.866)*ZDIA(I)+3.*(ZF+ZG)))
      XRLC=AIMAG(ZZE)/REAL(ZZE)
      EC=3.*EBUS(IRW)*ZDIA(I)*(Z0DIA(I)+2.*(ZF+ZG))/ZZ
      UBP(1004)=CABS(EC)
      EC=-3.*EBUS(IRW)*ZDIA(I)*(ZF+ZG)/ZZ
      UBP(1005)=CABS(EC)
C   LIST ITH BUS FAULT SUMMARIES ON OUTPUT FILE:
  150 WRITE(2,1010) IRW,ZF,ZG
      WRITE(2,1011) FAULTI,FAULTLG,FAULTLL,FALTLLG,XR,XRLG,XRLL,XRLLG,
     1UBP(1001),UBP(1004),UBP(1002),UBP(1005),UBP(1003),UBP(1005),
     2FAULTLB,XRLB,FAULTLC,XRLC
      IF(OUT.EQ.12.OR.OUT.EQ.10) GO TO 200
      IF(OUT.EQ.13.OR.OUT.EQ.14) GO TO 151
      WRITE(2,1012) (IUBP(J),DU(J),UBP(J),UBP(NBS+J),UBP(2*NBS+J),
     1J=1,NBS)
  151 WRITE(2,1031)
      WRITE(2,1032)
      MM=LL-1
      WRITE(2,1033) (L1(N),L2(N),CU(N),CUR(N),N=1,MM)
      GO TO 200
  160 WRITE(2,1010) IRW,ZF,ZG
      WRITE(2,1013) FAULTI,FAULTLG,XR,XRLG
      IF(OUT.EQ.12.OR.OUT.EQ.10) GO TO 200
      IF(OUT.EQ.13.OR.OUT.EQ.14) GO TO 151
      WRITE(2,1014) (IUBP(J),DU(J),UBP(J),UBP(NBS+J),UBP(2*NBS+J),
     1J=1,NBS)
  161 MM=LL-1
      WRITE(2,1046)
      WRITE(2,1030) (L1(N),L2(N),CU(N),CUR(N),N=1,MM)
      GO TO 200
  170 WRITE(2,1010) IRW,ZF,ZG
      WRITE(2,1021) FAULTLG,XRLG
      IF(OUT.EQ.12.OR.OUT.EQ.10) GO TO 200
      IF(OUT.EQ.13.OR.OUT.EQ.14) GO TO 171
      WRITE(2,1022) (IUBP(J),UBP(J),UBP(NBS+J),UBP(2*NBS+J),J=1,NBS)
  171 WRITE(2,1040)
      MM=LL-1
      WRITE(2,1041) (L1(N),L2(N),CUR(N),N=1,MM)
  200 CONTINUE
```

```
      ICOUNT=ICOUNT-1
      M=M+NBS
      IF(M.LT.NBUS) NBS=NBUS-M
      IF(NBS.GT.50) NBS=50
      IF(M.EQ.NBUS) M=0
      IF(ISYS.NE.0) GO TO 95
      IF(M.EQ.0) RETURN
      GO TO 106
  900 WRITE(2,1000) I
      GO TO 950
  901 WRITE(2,1001) I
      GO TO 950
  902 WRITE(2,1002) NBUS,(LIST(I),I=1,K)
      GO TO 950
  903 WRITE(2,1003) NOMU
      GO TO 950
  904 WRITE(2,1004) NBS
      GO TO 950
  905 WRITE(2,1005) I,ICD(I)
      GO TO 950
  906 WRITE(2,1006) LTRA(I),LTRB(I),LTRA(I)
      GO TO 950
  907 WRITE(2,1007) I
      GO TO 950
  908 WRITE(2,1008)
      GO TO 950
  909 WRITE(2,1017) ISS,IK,(JBP(I),I=1,IK)
      GO TO 950
  910 WRITE(2,1039) IUBP(I)
      GO TO 950
  911 WRITE(2,1038) LINA(L),LINB(L)
      GO TO 950
  912 WRITE(2,1048) C
      GO TO 950
  913 WRITE(2,1049)
      GO TO 950
  914 WRITE(2,1048) CC
      GO TO 950
  915 WRITE(2,1048) C1
      GO TO 950
  916 WRITE(2,1048) C2
      GO TO 950
  917 WRITE(2,1048) C3
  950 IERR=IERR+1
      RETURN
      END
```

```
      SUBROUTINE BUS(M)                                                 030480
      INTEGER CONEC                                                     030490
      COMPLEX ZBUS,ZOBUS,ZDIA,ZODIA,ZM,YCOUP,ZCOUP,EBUS,ZC,ZLL          030500
      COMMON /COMB/LINA(1450),LINB(1450),G(1450),B(1450),P(250),Q(250), 030510
     1LPHB(50),PHANG(50),LTRA(250),LTRB(250),TAP(250),TMN(250),V(250),  030520
     2TMX(250),IUBPP(250),ANG(250),IBUS(250),JBP(250),UBP(3000),        030530
     3BUSNAME(250),LPHA(50),LIST(250),IUBP(250),QMIN(250),QMAX(250),    030540
     4JBPP(250),UBPP(3000),JBP(3000),JBPP(3000),ICC(250),OLP(250),      030550
     5ZOI(1450),ZOR(1450),BDIA(250),CONEC(250),DLQ(250),IPHASE(250)     030560
      COMMON/COMC/ NA(250),NB(250),JCOL(1000),DJ(1000),IDB(250)         030570
      COMMON /CONST/ NBUS,NL,ISS,IPV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC      030580
     1,ITR1,ITR2,PTOL,QTOL,NLC                                          030590
      COMMON /SAVE/ IERR                                                030600
      COMMON /ZERO/LA(25),LB(25),LR(25),LS(25),ZM(25),YCOUP(8,8),       030610
     1ZCOUP(25),IJK(25),KJI(25),ITZ(25),ISAVE(8),ZDIA(75),ZODIA(75),    030620
     2ZBUS(2775),ZOBUS(2775),EBUS(250),ZC(75)                           030630
      COMMON /ZCONST/ NOMU,NBS,IROW,IMJT,IDUMM                          030640
 1000 FORMAT(1X,"ERROR IN POS. SEQ BUILDING ALGORITHM.  BUS",I4,        030650
     1" OR BUS",I4," SHOULD HAVE BEEN IN SUBSYSTEM BUS LIST BUT WASN'T")030660
 1001 FORMAT(1X,"ERROR IN POS. SEQ BUILDING ALGORITHM.  LINE",I4," TO", 030670
     1I4," SHOULD HAVE G(L) OR B(L) GREATER THAN ZERO."/)               030680
 1002 FORMAT(1X,"ERROR IN BUS(M) ROUTINE. NUMBER OF LINE ELEMENTS HAS EX030690
     1CEEDED ARRAY SIZE OF 75.  REDUCE SIZE OF SUBSYSTEM."/)            030700
C  CLEAR ALL ARRAYS AND RESTORE NA ARRAY. IUBP IS BUILT TO BE SUB-      030710
C  SYSTEM BUS LIST. L IS LINE ENTRY NUMBER FROM G(L) B(L) LIST.         030720
C  LOOP STARTING AT 100 TAKES EACH LINE(L) AND BUILDS SYSTEM.           030730
C  IF BUS IS NOT IN SUBSYSTEM LIST, IT IS DROPPED AT 90 TO 100.         030740
C  THE L NUMBERS COME FROM JBP() IN LOOP 90 OF FAULT.                   030750
      DO 9 I=1,75                                                       030760
      ZDIA(I)=0                                                         030770
      IUBP(I)=0                                                         030780
      ZC(I)=0                                                           030790
    9 CONTINUE                                                          030800
      DO 12 I=1,2775                                                    030810
      ZBUS(I)=0                                                         030820
   12 CONTINUE                                                          030830
      DO 11 I=1,NBUS                                                    030840
      NA(I)=CONEC(I)                                                    030850
   11 CONTINUE                                                          030860
      K=0                                                               030870
      DO 100 I=1,ISS                                                    030880
      ITEST=1                                                           030890
      L=JBP(I)                                                          030900
      JA=0                                                              030910
      JC=0                                                              030920
      JD=0                                                              030930
      IF(G(L).EQ.0..AND.B(L).EQ.0.) GO TO 88                            030940
      IF(LINB(L).EQ.0) GO TO 25                                         030950
          DO 1 J=1,K                                                    030960
          IF(LINA(L).EQ.IUBP(J)) GO TO 2                                030970
    1     CONTINUE                                                      030980
      ITEST=0                                                           030990
    2 JA=J                                                              031000
          DO 3 J=1,K                                                    031010
          IF(LINB(L).EQ.IUBP(J)) GO TO 4                                031020
    3     CONTINUE                                                      031030
      IF(ITEST.EQ.0) GO TO 899                                          031040
```

```
C  LINE IS A BRANCH FROM "P" TO "Q"; THEREFORE SWAP P AND Q:
      L1=LINB(L)
      L2=LINA(L)
      JC=J
      JD=JA
      GO TO 5
    4 L1=LINA(L)
      L2=LINB(L)
      JC=JA
      JD=J
      IF(ITEST.EQ.1) GO TO 15
C  LINE IS A BRANCH FROM Q TO P; ADD NEW BUS TO SYSTEM:
    5 JJ=K
      K=K+1
C  K IS CHECKED TO PREVENT OVER-RUN OF ARRAYS ZBUS,ZDIA,ZC.
C  SIZE OF ZBUS IS DETERMINED BY K AND IADD ROUTINE.
      IF(K.GT.75.) GO TO 902
      IUBP(K)=L1
           DO 6 J=1,JJ
           IF(IUBP(J).EQ.L2) GO TO 7
    6      CONTINUE
      GO TO 900
    7      DO 10 N=1,JJ
           N1=IADD(N,K)
           IF(N.EQ.J) GO TO 8
           N2=IADD(N,J)
           ZBUS(N1)=ZBUS(N2)
           GO TO 19
    8      ZBUS(N1)=ZDIA(J)
   19 CONTINUE
   10        CONTINUE
      ZDIA(K)=ZDIA(J)+1./CMPLX(G(L),B(L))
      GO TO 90
C  LINE IS A LOOP:
   15 K1=K2=0
          DO 16 J=1,K
           IF(IUBP(J).EQ.L1) K1=J
           IF(IUBP(J).EQ.L2) K2=J
   16      CONTINUE
           DO 20 J=1,K
           IF(J.EQ.K1) GO TO 17
           IF(J.EQ.K2) GO TO 18
           N1=IADD(J,K1)
           N2=IADD(J,K2)
           ZC(J)=ZBUS(N1)-ZBUS(N2)
           GO TO 20
   17      N2=IADD(J,K2)
           ZC(J)=ZDIA(K1)-ZBUS(N2)
           GO TO 20
   18      N1=IADD(J,K1)
           ZC(J)=ZBUS(N1)-ZDIA(K2)
   20      CONTINUE
      N1=IADD(K1,K2)
      IF(K2.LT.K1) N1=IADD(K2,K1)
      IF(CMPLX(G(L),B(L)).EQ.0) GO TO 901
      ZLL=ZDIA(K1)+ZDIA(K2)-2.*ZBUS(N1)+1./CMPLX(G(L),B(L))
      GO TO 80
```

```
      C  LINE HAS P-NODE THE REF:
      25      DO 26 J=1,K
              IF(LINA(L).EQ.IUBP(J)) GO TO 30
      26      CONTINUE
      C  LINE IS A BRANCH FROM REF. TO "Q": ADD NEW BUS TO SYSTEM:
         JJ=K
         K=K+1
         IUBP(K)=L2=LINA(L)
         IF(CMPLX(G(L),B(L)).EQ.0) GO TO 901
         ZDIA(K)=1./CMPLX(G(L),B(L))
         L1=0
         GO TO 90
      C  LINE IS A LOOP CLOSING ELEMENT (REF. TO "Q"): ADD LOOP ELEMENT:
      30 L1=0
         L2=LINA(L)
         JD=J
              DO 40 N=1,K
              IF(J.EQ.N) GO TO 35
              N1=IADD(N,J)
              ZC(N)=ZBUS(N1)
              GO TO 40
      35      ZC(N)=ZDIA(J)
      40      CONTINUE
         IF(CMPLX(G(L),B(L)).EQ.0) GO TO 901
         ZLL=ZDIA(J)+1./CMPLX(G(L),B(L))
      C  ELIMINATE LOOP AXIS BY KRON REDUCTION:
      80      DO 85 II=1,K
              DO 84 JJ=1,K
              IF(II.EQ.JJ) GO TO 82
              IF(II.GT.JJ) GO TO 83
              N1=IADD(II,JJ)
              ZBUS(N1)=ZBUS(N1)-ZC(II)*ZC(JJ)/ZLL
              GO TO 83
      82      ZDIA(II)=ZDIA(II)-ZC(II)*ZC(II)/ZLL
      83 CONTINUE
      84      CONTINUE
      85      CONTINUE
         GO TO 90
      C  REDUCE BUS CONNECTION COUNT FOR BUSSES: ELIMINATE PTH OR QTH AXIS
      C  IF ALL CONNECTIONS TO THAT BUS ARE COMPLETE AND THE BUS IS NOT IN
      C  THE AREA OF STUDY:
      88 L1=LINB(L)
         L2=LINA(L)
      90 CONTINUE
         IF(L1.EQ.0) GO TO 95
         NA(L1)=NA(L1)-1
         IF(NA(L1).NE.0) GO TO 95
              DO 92 N=1,NBS
              IF(NB(M+N).EQ.L1) GO TO 95
      92      CONTINUE
      C  ELIMINATE PTH AXIS:
         CALL SWAPZ(JC,K)
         K=K-1
      95 NA(L2)=NA(L2)-1
         IF(NA(L2).NE.0) GO TO 100
              DO 96 N=1,NBS
              IF(NB(M+N).EQ.L2) GO TO 100

      96      CONTINUE
      C  ELIMINATE QTH AXIS AND ADJUST INDEX
         IF(K.LT.JD) 50,60
      50 JD=JC
      60 CALL SWAPZ(JD,K)
         K=K-1
     100 CONTINUE
         RETURN
     899 WRITE(2,*) "BUS LIST FOLLOWS"
         WRITE(2,*) (IUBP(J),J=1,K)
     900 WRITE(2,1000) LINA(L),LINB(L)
         GO TO 910
     901 WRITE(2,1001) LINA(L),LINB(L)
         GO TO 910
     902 WRITE(2,1002)
     910 IERR=IERR+1
         RETURN
         END
```

```
      SUBROUTINE BUS0(M)                                                032370
      INTEGER CONEC                                                     032380
      COMPLEX ZZ,OFFDIAG,DIAG,ZLL,ZDIA,ZODIA,ZBUS,ZOBUS,YCOUP,ZC,       032390
     1ZCOUP,ZM,EBUS                                                     032400
      COMMON /COMB/LINA(1450),LINB(1450),G(1450),B(1450),P(250),Q(250), 032410
     1LP49(50),PHANG(50),LTRA(250),LTRB(250),TAP(250),TMN(250),V(250),  032420
     2TMX(250),IUBPP(250),ANG(250),IBUS(250),DBP(250),UBP(3000),        032430
     3BUSNAME(250),LPHA(50),LIST(250),IUBP(250),QMIN(250),QMAX(250),    032440
     4JBPP(250),UBPP(3000),JBP(3000),JBPP(3000),ICC(250),DLP(250),      032450
     5Z0I(1450),Z0R(1450),BDIA(250),CONEC(250),DLQ(250),IPHASE(250)     032460
      COMMON/COMC/ NA(250),NB(250),JCOL(1000),DJ(1000),IOB(250)         032470
      COMMON /CONST/ NBUS,NL,ISS,IPV,LL1,LL2,LL3,LL4,NOTR,IZ,NOLTC      032480
     1,ITR1,ITR2,PTOL,QTOL,NLC                                          032490
      COMMON /SAVE/ IERR                                                032500
      COMMON /ZERO/LA(25),LB(25),LR(25),LS(25),ZM(25),YCOUP(8,8),       032510
     1ZCOUP(25),IJK(25),KJI(25),ITT(25),ISAVE(8),ZDIA(75),ZODIA(75),    032520
     2ZBUS(2775),ZOBUS(2775),EBUS(250),ZC(75)                           032530
      COMMON /ZCONST/ NOMU,NBS,IROW,INJT,IDUMM                          032540
 1000 FORMAT(1X,"ERROR IN ZERO SEQ. BUILDING ALGORITHM.  BUS",I4,       032550
     1"OR BUS",I4,"SHOULD HAVE BEEN IN SYSTEM LIST, BUT WASN'T!!"/)     032560
 1001 FORMAT(1X,"ERROR IN ZERO SEQ.BUILDING ALGORITHM. LINE FROM",I4,   032570
     1"TO",I4," MUST HAVE ZERO SEQ. IMPEDANCE NOT EQ. TO 0."/)          032580
 1002 FORMAT(1X,"ERROR IN BUS0 ROUTINE. NUMBER OF LINE ELEMENTS HASEXCEE032590
     1DED 75 ARRAY SIZE. REDUCE SIZE OF SUBSYSTEM."/)                   032600
C  SEE COMMENTS IN BUS(M) ROUTINE,SAME LOCATION AS HERE.DIFFERENCE      032610
C  IS THAT BUS0(M) HAS ROUTINES FOR MUTUAL IMPEDANCES.                  032620
      DO 1 I=1,75                                                       032630
      IUBP(I)=0                                                         032640
      ZODIA(I)=0                                                        032650
      ZC(I)=0                                                           032660
    1 CONTINUE                                                          032670
      DO 11 II=1,NBUS                                                   032680
      NA(II)=CONEC(II)                                                  032690
   11 CONTINUE                                                          032700
      DO 9 I=1,2775                                                     032710
      ZOBUS(I)=0                                                        032720
    9 CONTINUE                                                          032730
      K=0                                                               032740
      DO 100 I=1,ISS                                                    032750
      ITEST=1                                                           032760
      L=JBP(I)                                                          032770
      JA=0                                                              032780
      JC=0                                                              032790
      JD=0                                                              032800
      IF(LINB(L).EQ.0) GO TO 50                                         032810
           DO 2 J=1,K                                                   032820
           IF(LINA(L).EQ.IUBP(J)) GO TO 3                               032830
    2      CONTINUE                                                     032840
      ITEST=0                                                           032850
    3 JA=J                                                              032860
           DO 4 J=1,K                                                   032870
            IF(LINB(L).EQ.IUBP(J)) GO TO 5                              032880
    4      CONTINUE                                                     032890
      IF(ITEST.EQ.0) GO TO 898                                          032900
C  LINE IS A BRANCH FROM "P" TO "Q": SWAP P AND Q:                      032910
      L1=LINB(L)                                                        032920
      L2=LINA(L)                                                        032930
```

```
      JC=J
      JD=JA
      GO TO 6
    5 L1=LINA(L)
      L2=LINB(L)
      JC=JA
      JD=J
      IF(ITEST.EQ.1) GO TO 25
C  LINE IS A BRANCH FROM "Q" IN SYSTEM TO NEW BUS "P"; ADD NEW BUS;
C  THEN CHK FOR MUTUALS:
    6 JJ=K
      K=K+1
C  K IS CHECKED TO PREVENT OVER-RUN OF ARRAYS ZOBUS,ZODIA,ZC.
C  SIZE OF ZOBUS ARRAY IS DETERMINED BY K AND IADD ROUTINE.
      IF(K.GT.75.) GO TO 902
      IUBP(K)=L1
      ZZ=CMPLX(ZOR(L),ZOI(L))
      IF(NOMU.EQ.0) GO TO 20
      CALL MUTEST(L1,L2,ZZ)
      IF(IERR.NE.0) RETURN
      IF(IROW.EQ.0) GO TO 20
C  BRANCH HAS MUTUALS AND IS NOT THE FIRST LINE OF MUTUALLY COUPLED
C  SET; ADD BRANCH W/MUTUALS:
         DO 7 J=1,JJ
         IF(IUBP(J).EQ.L2) GO TO 8
    7    CONTINUE
      GO TO 900
    8 IQ=J
         DO 10 J=1,JJ
         ZLL=OFFDIAG(JJ,J)
         IF(IERR.NE.0) RETURN
         N1=IADD(J,IQ)
         N2=IADD(J,K)
         ZOBUS(N2)=ZOBUS(N1)+ZLL/YCOUP(1,1)
   10    CONTINUE
      ZLL=DIAG(JJ,K)
      N1=IADD(IQ,K)
      ZODIA(K)=ZOBUS(N1)+((1.0,0.)+ZLL)/YCOUP(1,1)
      GO TO 90
C  BRANCH DOES NOT HAVE MUTUALS, OR IS THE FIRST LINE OF A MUTUALLY
C  COUPLED SET; ADD BRANCH WO/MUTUALS:
   20    DO 21 J=1,JJ
         IF(IUBP(J).EQ.L2) GO TO 22
   21    CONTINUE
      GO TO 900
   22    DO 24 N=1,JJ
         N1=IADD(N,K)
         IF(N.EQ.J) GO TO 23
         N2=IADD(N,J)
         ZOBUS(N1)=ZOBUS(N2)
         GO TO 24
   23    ZOBUS(N1)=ZODIA(J)
   24    CONTINUE
      ZODIA(K)=ZODIA(J)+ZZ
      GO TO 90
C  LINE IS LOOP CLOSING ELEMENT; CHK FOR MUTUALS:
   25 ZZ=CMPLX(ZOR(L),ZOI(L))
```

```
      IF(NOMU.EQ.0) GO TO 41
      CALL MUTEST(L1,L2,ZZ)
      IF(IERR.NE.0) RETURN
      IF(IROW.EQ.0) GO TO 41
C  LOOP HAS MUTUALS AND IS NOT THE FIRST LINE OF A MUTUALLY COUPLED
C  SET: ADD LOOP W/MUTUALS:
      K1=K2=0
         DO 26 J=1,K
         IF(IUBP(J).EQ.L1) K1=J
         IF(IUBP(J).EQ.L2) K2=J
   26    CONTINUE
      IF(K1.EQ.0.OR.K2.EQ.0) GO TO 900
         DO 30 J=1,K
         ZLL=OFFDIAG(K,J)
         IF(IERR.NE.0) RETURN
         N1=IADD(J,K1)
         N2=IADD(J,K2)
         N3=IADD(J,K+1)
         ZOBUS(N3)=ZOBUS(N1)-ZOBUS(N2)+ZLL/YCOUP(1,1)
   30    CONTINUE
      ZLL=DIAG(K,K)
      N1=IADD(K1,K+1)
      N2=IADD(K2,K+1)
      ZODIA(K+1)=ZOBUS(N1)-ZOBUS(N2)+((1.0,0.)+ZLL)/YCOUP(1,1)
      GO TO 80
C  LOOP DOES NOT HAVE MUTUALS, OR IS THE FIRST LINE OF MUTUALLY
C  COUPLED SET: ADD LOOP NO/MUTUALS:
   41 K1=K2=0
         DO 42 J=1,K
         IF(IUBP(J).EQ.L1) K1=J
         IF(IUBP(J).EQ.L2) K2=J
   42    CONTINUE
      IF(K1.EQ.0.OR.K2.EQ.0) GO TO 900
         DO 45 J=1,K
         IF(J.EQ.K1) GO TO 43
         IF(J.EQ.K2) GO TO 44
         N1=IADD(J,K1)
         N2=IADD(J,K2)
         ZC(J)=ZOBUS(N1)-ZOBUS(N2)
         GO TO 45
   43    N2=IADD(J,K2)
         ZC(J)=ZODIA(K1)-ZOBUS(N2)
         GO TO 45
   44    N1=IADD(J,K1)
         ZC(J)=ZOBUS(N1)-ZODIA(K2)
   45    CONTINUE
      N1=IADD(K1,K2)
      ZLL=ZODIA(K1)+ZODIA(K2)-2.*ZOBUS(N1)+ZZ
      GO TO 80
C  LINE HAS ONE NODE THE REF: CHK IF OTHER NODE IS IN SYSTEM:
   50 ZZ=CMPLX(ZOR(L),ZOI(L))
         DO 51 J=1,K
         IF(LINA(L).EQ.IUBP(J)) GO TO 60
   51    CONTINUE
C  LINE IS BRANCH FROM REF. TO "J": ADD NEW BUS TO SYSTEM:
      L1=0
      JJ=K
```

```
      K=K+1
      IUBP(K)=L2=LINA(L)
      Z0DIA(K)=ZZ
      Z0DIA(K)=ZZ
      GO TO 90
C   LINE IS LOOP CLOSING ELEMENT (REF. TO "Q"): ADD LOOP CLOSING
C   ELEMENT:
   60 L1=0
      L2=LINA(L)
            DO 65 N=1,K
            IF(J.EQ.N) GO TO 61
            N1=IADD(N,J)
            ZC(N)=Z0BUS(N1)
            GO TO 65
   61       ZC(N)=Z0DIA(J)
   65       CONTINUE
      ZLL=Z0DIA(J)+ZZ
C   ELIMINATE LOOP AXIS BY KRON REDUCTION:
   80 IF(ZLL.EQ.0) GO TO 999
            DO 85 II=1,K
            DO 84 JJ=1,K
            IF(II.EQ.JJ) GO TO 83
            IF(II.GT.JJ) GO TO 84
            N1=IADD(II,JJ)
            Z0BUS(N1)=Z0BUS(N1)-ZC(II)*ZC(JJ)/ZLL
            GO TO 84
   83       Z0DIA(II)=Z0DIA(II)-ZC(II)*ZC(II)/ZLL
   84       CONTINUE
   85       CONTINUE
C   REDUCE BUS CONNECTION COUNT FOR BUSSES:  ELIMINATE PTH OR QTH AXIS
C   IF ALL CONNECTIONS TO THAT BUS ARE COMPLETE AND THE BUS IS NOT IN
C   THE AREA OF STUDY:
   90 IF(L1.EQ.0) GO TO 95
      NA(L1)=NA(L1)-1
      IF(NA(L1).NE.0) GO TO 95
            DO 92 N=1,NBS
            IF(NB(M+N).EQ.L1) GO TO 95
   92       CONTINUE
      CALL SWAPZ0(JC,K)
      K=K-1
   95 NA(L2)=NA(L2)-1
      IF(NA(L2).NE.0) GO TO 100
            DO 96 N=1,NBS
            IF(NB(M+N).EQ.L2) GO TO 100
   96       CONTINUE
C   ELIMINATE QTH AXIS:
      IF(K.LT.JD) 97,98
   97 JD=JC
   98 CALL SWAPZ0(JD,K)
      K=K-1
  100 CONTINUE
      RETURN
  898 WRITE(2,*) "BUS LIST FOLLOWS"
      WRITE(2,*) (IUBP(J), J=1,K)
      GO TO 900
  899 WRITE(2,1001) L1,L2
      GO TO 910

  900 WRITE(2,1000) LINA(L),LINB(L)
      GO TO 910
  902 WRITE(2,1002)
  910 IERR=IERR+1
      RETURN
      END
```

```
      SUBROUTINE MUTEST(I1,I2,ZZ)                                       034710
      INTEGER S1,S2                                                     034720
      COMPLEX YCOUP,ZM,ZZ,ZCOUP,ZBUS,Z0BUS,ZDIA,Z0DIA,EBUS,ZC           034730
      COMMON /ZERO/LA(25),LB(25),LR(25),LS(25),ZM(25),YCOUP(8,8),       034740
     1ZCOUP(25),IJK(25),KJI(25),ITZ(25),ISAVE(8),ZDIA(75),Z0DIA(75),    034750
     2ZBUS(2775),Z0BUS(2775),EBUS(250),ZC(75)                           034760
      COMMON /ZCONST/ NOMU,NBS,IROW,IMUT,IDUMM                          034770
      COMMON /SAVE/ IERR                                                034780
      IROW=0                                                            034790
      DO 10 I=1,NOMU                                                    034800
      IF(LA(I).NE.I1) GO TO 1                                           034810
      IF(LB(I).EQ.I2) GO TO 11                                          034820
      GO TO 2                                                           034830
    1 IF(LB(I).NE.I1) GO TO 2                                           034840
      IF(LA(I).EQ.I2) GO TO 11                                          034850
    2 IF(LR(I).NE.I1) GO TO 3                                           034860
      IF(LS(I).EQ.I2) GO TO 12                                          034870
      GO TO 10                                                          034880
    3 IF(LS(I).NE.I1) GO TO 10                                          034890
      IF(LS(I).EQ.I2) GO TO 12                                          034900
   10 CONTINUE                                                          034910
C  LINE DOES NOT HAVE MUTUALS: RETURN TO BUSB TO CONTINUE PROCESSING    034920
C  LINE.                                                                034930
      RETURN                                                            034940
C  LINE DOES HAVE MUTUALS: THE OTHER LINE IS DEFINED BY LR(I) AND LS(I).034950
   11 L1=LR(I)                                                          034960
      L2=LS(I)                                                          034970
      GO TO 15                                                          034980
C  LINE DOES HAVE MUTUALS: THE OTHER LINE IS DEFINED BY LA(I) AND LB(I).034990
   12 L1=LA(I)                                                          035000
      L2=LB(I)                                                          035010
C  CHK TO SEE IF OTHER LINE HAS ALREADY BEEN ADDED TO SYSTEM.           035020
   15 IF(IMUT.EQ.0) GO TO 20                                            035030
      DO 19 I=1,IMUT                                                    035040
      IF(IJK(I).NE.L1) GO TO 16                                         035050
      IF(KJI(I).EQ.L2) GO TO 21                                         035060
      GO TO 19                                                          035070
   16 IF(KJI(I).NE.L1) GO TO 19                                         035080
      IF(IJK(I).EQ.L2) GO TO 21                                         035090
   19 CONTINUE                                                          035100
C  THIS IS THE FIRST LINE OF THE MUTUALLY COUPLED SET: ADD LINE TO      035110
C  MUTUAL BUILDING TABLE: RETURN.                                       035120
   20 IMUT=IMUT+1                                                       035130
      IDUMM=IDUMM+1                                                     035140
      ITZ(IMUT)=IDUMM                                                   035150
      IJK(IMUT)=I1                                                      035160
      KJI(IMUT)=I2                                                      035170
      ZCOUP(IMUT)=ZZ                                                    035180
      RETURN                                                            035190
C  NEW LINE IS COUPLED TO LINE ALREADY IN SYSTEM: ADD NEW LINE TO       035200
C  MUTUAL BUILDING TABLE: FORM MUTUAL COUPLING MATRIX FOR THIS          035210
C  COUPLED SET.                                                         035220
   21 IMUT=IMUT+1                                                       035230
      IST=IMUT+1                                                        035240
      ITZ(IMUT)=ITZ(I)                                                  035250
      IJK(IMUT)=I1                                                      035260
      KJI(IMUT)=I2                                                      035270
```

```
      ZCOUP(IMUT)=ZZ
C  THE FOLLOWING SECTION CONSTRUCTS THE MUTUAL COUPLING MATRIX TO BE
C  USED BY THE BUSS BUILDING ALGORITHM FOR LINES WITH MUTUALS.
      II=KK+1
      DO 80 I=1,IST
      IF(I.EQ.IST) GO TO 80
      JJ=IST-I
      IF(ITZ(JJ).NE.ITZ(IMUT)) GO TO 80
      IROW=IROW+1
      ISAVE(IROW)=JJ
      YCOUP(IROW,IROW)=ZCOUP(JJ)
      IF(JJ.EQ.IMUT) GO TO 80
      S1=I1
      S2=I2
      JK=1
   22     DO 50 J=1,NOMJ
          IF(LA(J).NE.S1) GO TO 25
          IF(LB(J).NE.S2) GO TO 30
          IF(LR(J).NE.IJK(JJ)) GO TO 40
          IF(LS(J).EQ.KJI(JJ)) GO TO 55
          GO TO 50
   25     IF(LB(J).NE.S1) GO TO 30
          IF(LA(J).NE.S2) GO TO 30
          IF(LR(J).NE.IJK(JJ)) GO TO 40
          IF(LS(J).EQ.KJI(JJ)) GO TO 55
          GO TO 50
   30     IF(LR(J).NE.S1) GO TO 35
          IF(LS(J).NE.S2) GO TO 50
          IF(LA(J).NE.IJK(JJ)) GO TO 45
          IF(LB(J).EQ.KJI(JJ)) GO TO 55
          GO TO 50
   35     IF(LS(J).NE.S1) GO TO 50
          IF(LR(J).NE.S2) GO TO 50
          IF(LA(J).NE.IJK(JJ)) GO TO 45
          IF(LB(J).EQ.KJI(JJ)) GO TO 55
          GO TO 50
   40     IF(LS(J).NE.IJK(JJ)) GO TO 50
          IF(LR(J).EQ.KJI(JJ)) GO TO 55
          GO TO 50
   45     IF(LB(J).NE.IJK(JJ)) GO TO 50
          IF(LA(J).EQ.KJI(JJ)) GO TO 55
   50     CONTINUE
      YCOUP(JK,IROW)=CMPLX(0.,0.)
      YCOUP(IROW,JK)=CMPLX(0.,0.)
      GO TO 56
   55 YCOUP(JK,IROW)=YCOUP(IROW,JK)=ZM(J)
   56 JK=JK+1
      IF(JK.EQ.IROW) GO TO 80
      S1=IJK(ISAVE(JK))
      S2=KJI(ISAVE(JK))
      GO TO 22
   80 CONTINUE
C  MUTUAL IMPEDANCE COUPLING MATRIX IS COMPLETE. CALL SUBROUTINE
C  TO INVERT IMPEDANCE COUPLING MATRIX TO FORM ADMITTANCE COUPLING
C  MATRIX.
      NN=2*IROW
      CALL CPLXINV(YCOUP,IROW,NN)

      RETURN
      END
```

```
      SUBROUTINE CPLXINV(A,N,NN)
      COMPLEX A(N,NN),AL
      EPSIL=1.E-8
      DO 3 I=1,N
      DO 3 J=1,N
      IF(I.EQ.J) GO TO 2
      A(I,J+N)=CMPLX(0.,0.)
      GO TO 3
    2 A(I,J+N)=CMPLX(1.,0.)
    3 CONTINUE
      DO 50 IP=1,N
      IM=IP
      IST=IP+1
      IF(IP.EQ.N) GO TO 11
            DO 10 I=IST,N
            Z1=CABS(A(IM,IP))
            Z2=CABS(A(I,IP))
            IF(Z1.GE.Z2) GO TO 10
            IM=I
   10       CONTINUE
   11 Z1=CABS(A(IM,IP))
      IF(Z1.GE.EPSIL) GO TO 13
            WRITE(1,1000) A(IM,IP)
 1000 FORMAT(1X,"PIVOT ELEMENT= ",E20.10/)
            Z1=CABS(A(IM,IP))
            IF(Z1.EQ.0.) GO TO 70
   13       IF(IM.EQ.IP) GO TO 20
            DO 15 J=IP,NN
            AL=A(IP,J)
            A(IP,J)=A(IM,J)
   15       A(IM,J)=AL
   20 AL=A(IP,IP)
      A(IP,IP)=CMPLX(1.,0.)
            DO 25 J=IST,NN
   25       A(IP,J)=A(IP,J)/AL
            DO 40 I=1,N
            IF(I.EQ.IP) GO TO 40
            AL=A(I,IP)
                  DO 35 J=IP,NN
   35             A(I,J)=A(I,J)-AL*A(IP,J)
   40       CONTINUE
   50 CONTINUE
      DO 60 I=1,N
      DO 60 J=1,N
   60 A(I,J)=A(I,J+N)
   70 RETURN
      END

      SUBROUTINE SWAPZ(IR,K)
      INTEGER CONEC
      COMPLEX ZBUS,ZOBUS,ZDIA,ZODIA,ZM,YCOUP,ZCOUP,EBUS,ZC
      COMMON /COMB/LINA(1450),LINB(1450),G(1450),B(1450),P(250),Q(250),
     1LP48(50),PHANG(50),LTRA(250),LTRB(250),TAP(250),TMN(250),V(250),
     2TMX(250),IUBPP(250),ANG(250),IBUS(250),DBP(250),UBP(3000),
     3BUSNAME(250),LPHA(50),LIST(250),IUBP(250),QMIN(250),QMAX(250),
     4DBPP(250),UBPP(3000),JBP(3000),JBPP(3000),ICC(250),DLP(250),
     5Z0I(1450),Z0R(1450),BDIA(250),CONEC(250),DLQ(250),IPHASE(250)
      COMMON /ZERO/LA(25),LB(25),LR(25),LS(25),ZM(25),YCOUP(8,8),
     1ZCOUP(25),IJK(25),KJI(25),ITZ(25),ISAVE(8),ZDIA(75),ZODIA(75),
     2ZBUS(2775),ZOBUS(2775),EBUS(250),ZC(75)
      COMMON /ZCONST/ NOMJ,NBS,IROW,IMJT,IDUMM
      IF(IR.EQ.K) GO TO 25
      DO 20 I=1,K
      IF(I.EQ.IR) GO TO 15
      IF(I.EQ.K) GO TO 20
      N1=IADD(I,IR)
      N2=IADD(I,K)
      ZBUS(N1)=ZBUS(N2)
      ZBUS(N2)=CMPLX(0.,0.)
      GO TO 20
   15 ZDIA(IR)=ZDIA(K)
      ZDIA(K)=CMPLX(0.,0.)
   20 CONTINUE
      IUBP(IR)=IUBP(K)
      RETURN
   25 DO 26 J=1,K
      IF(J.EQ.K) GO TO 30
      N1=IADD(J,K)
      ZBUS(N1)=CMPLX(0.,0.)
   26 CONTINUE
   30 ZDIA(K)=CMPLX(0.,0.)
      RETURN
      END
```

```
      SUBROUTINE SHAPZB(IR,K)
      INTEGER CONEC
      COMPLEX ZBUS,ZBBUS,ZDIA,ZBDIA,ZM,YCOUP,ZCOUP,EBUS,ZC
      COMMON /COMB/LINA(1450),LINB(1450),G(1450),B(1450),P(250),Q(250),
     1_PHB(50),PHANG(50),LTRA(250),LTRB(250),TAP(250),TMN(250),V(250),
     2TMX(250),IUBPP(250),ANG(250),IBUS(250),DBP(250),UBP(3000),
     3BUSNAME(250),LPHA(50),LIST(250),IUBP(250),QMIN(250),QMAX(250),
     4DBPP(250),UBPP(3000),JBP(3000),JBPP(3000),ICC(250),DLP(250),
     5ZBI(1450),ZBR(1450),BDIA(250),CONEC(250),DLQ(250),IPHASE(250)
      COMMON /ZERO/LA(25),LB(25),LR(25),LS(25),ZM(25),YCOUP(8,8),
     1ZCOUP(25),IJK(25),KJI(25),ITZ(25),ISAVE(8),ZDIA(75),ZBDIA(75),
     2ZBUS(2775),ZBBUS(2775),EBUS(250),ZC(75)
      COMMON /ZCONST/ NOMU,NBS,IROW,IMJT,IDUMM
      IF(IR.EQ.K) GO TO 25
      DO 20 I=1,K
      IF(I.EQ.IR) GO TO 15
      IF(I.EQ.K) GO TO 20
      N1=IADD(I,IR)
      N2=IADD(I,K)
      ZBBUS(N1)=ZBBUS(N2)
      ZBBUS(N2)=CMPLX(0.,0.)
      GO TO 20
   15 ZBDIA(IR)=ZBDIA(K)
      ZBDIA(K)=CMPLX(0.,0.)
   20 CONTINUE
      IUBP(IR)=IUBP(K)
      RETURN
   25 DO 25 J=1,K
      IF(J.EQ.K) GO TO 30
      N1=IADD(J,K)
      ZBBUS(N1)=CMPLX(0.,0.)
   26 CONTINUE
   30 ZBDIA(K)=CMPLX(0.,0.)
      RETURN
      END

      COMPLEX FUNCTION OFFDIAG(JJ,JC)
      INTEGER CONEC,S1,S2
      COMPLEX ZBUS,ZBBUS,ZDIA,ZBDIA,ZM,YCOUP,ZCOUP,EBUS,ZC
      COMMON /COMB/LINA(1450),LINB(1450),G(1450),B(1450),P(250),Q(250),
     1_PHB(50),PHANG(50),LTRA(250),LTRB(250),TAP(250),TMN(250),V(250),
     2TMX(250),IUBPP(250),ANG(250),IBUS(250),DBP(250),UBP(3000),
     3BUSNAME(250),LPHA(50),LIST(250),IUBP(250),QMIN(250),QMAX(250),
     4DBPP(250),UBPP(3000),JBP(3000),JBPP(3000),ICC(250),DLP(250),
     5ZBI(1450),ZBR(1450),BDIA(250),CONEC(250),DLQ(250),IPHASE(250)
      COMMON /ZERO/LA(25),LB(25),LR(25),LS(25),ZM(25),YCOUP(8,8),
     1ZCOUP(25),IJK(25),KJI(25),ITZ(25),ISAVE(8),ZDIA(75),ZBDIA(75),
     2ZBUS(2775),ZBBUS(2775),EBUS(250),ZC(75)
      COMMON /SAVE/ IERR
      COMMON /ZCONST/ NOMU,NBS,IROW,IMJT,IDUMM
      OFFDIAG=CMPLX(0.,0.)
      DO 10 I=2,IROW
      S1=S2=0
          DO 1 J=1,JJ
          IF(IUBP(J).EQ.IJK(ISAVE(I))) S1=J
          IF(IUBP(J).EQ.KJI(ISAVE(I))) S2=J
    1     CONTINUE
      IF(S1.EQ.0.OR.S2.EQ.0) GO TO 20
      IF(S1.EQ.JC) GO TO 5
      IF(S2.EQ.JC) GO TO 6
      N1=IADD(JC,S1)
      N2=IADD(JC,S2)
      OFFDIAG=OFFDIAG+(ZBBUS(N1)-ZBBUS(N2))*YCOUP(1,I)
      GO TO 10
    5 N2=IADD(JC,S2)
      OFFDIAG=OFFDIAG+(ZBDIA(S1)-ZBBUS(N2))*YCOUP(1,I)
      GO TO 10
    6 N1=IADD(JC,S1)
      OFFDIAG=OFFDIAG+(ZBBUS(N1)-ZBDIA(S2))*YCOUP(1,I)
   10 CONTINUE
      RETURN
   20 WRITE(1,100) I,IJK(ISAVE(I)),KJI(ISAVE(I))
      IERR=IERR+1
  100 FORMAT(1X,"SUBROUTINE BUSB:  ERROR BETWEEN MUTUAL TABLE AND SYSTEM
     1BUS LIST (IUBP)."/T5,"WORKING ON ROW",I3," YCOUP MATRIX."/
     2T5,"R=",I4," AND  S=",I4/)
      RETURN
      END
```

```
      COMPLEX FUNCTION DIAG(JJ,JC)
      INTEGER CONEC,S1,S2
      COMPLEX ZBUS,ZBBUS,ZDIA,ZBDIA,ZM,YCOUP,ZCOUP
      COMMON /COMB/LINA(1450),LINB(1450),G(1450),B(1450),P(250),Q(250),
     1LPHB(50),PHANG(50),LTRA(250),LTRB(250),TAP(250),TMN(250),V(250),
     2TMX(250),IUBPP(250),ANG(250),TAJS(250),DBP(250),UBP(3000),
     3BUSNAME(250),LPHA(50),LIST(250),IUBP(250),QMIN(250),QMAX(250),
     4DBPP(250),UBPP(3000),JBP(3000),JBPP(3000),ICC(250),DLP(250),
     5ZBI(1450),ZBR(1450),BDIA(250),CONEC(250),DLQ(250),IPHASE(250)
      COMMON /ZERO/LA(25),LB(25),LR(25),LS(25),ZM(25),YCOUP(8,8),
     1ZCOUP(25),IJK(25),KJI(25),ITZ(25),ISAVE(8),ZDIA(75),ZBDIA(75),
     2ZBUS(2775),ZBBUS(2775),EBUS(250),ZC(75)
      COMMON /ZCONST/ NOMU,NBS,IROW,IMUT,IDUMM
      DIAG=CMPLX(0.,0.)
      DO 10 I=2,IROW
          DO 5 J=1,JJ
          IF(IUBP(J).EQ.IJK(ISAVE(I))) S1=J
          IF(IUBP(J).EQ.KJI(ISAVE(I))) S2=J
    5     CONTINUE
      N1=IADD(S1,JJ+1)
      N2=IADD(S2,JJ+1)
      DIAG=DIAG+(ZBBUS(N1)-ZBBUS(N2))*YCOUP(1,I)
   10 CONTINUE
      RETURN
      END

      COMPLEX FUNCTION CPLXV(EA,EB)
      ETEMP=EB
      ETEMP=0.01745329*ETEMP
      E1=EA*COS(ETEMP)
      E2=EA*SIN(ETEMP)
      CPLXV=CMPLX(E1,E2)
      RETURN
      END

      FUNCTION IADD(I,J)
      III=I
      JJJ=J
      IF(III.LT.JJJ) GO TO 10
      TEMP=JJJ
      JJJ=III
      III=TEMP
   10 IADD=75*(III-1)-((III*III-III)/2)+JJJ-III
      RETURN
      END
```

Vita

Jesse Allen Underwood, Jr. was born in Renovo, Pennsylvania on June 29, 1941. He graduated from Northwestern High School in Albion, Pennsylvania in 1959 and then entered Edinboro State College, Edinboro, Pennsylvania. Graduating in 1963 with a Bachelor of Science degree in Education, he entered the United States Air Force through the Officer Training School at Lackland AFB, Texas, receiving his commission in 1964. After attending the Electronics Systems Officer Course at Keesler, AFB, Mississippi in 1965, he served at radar stations in Benton, Pennsylvania and Antigo, Wisconsin as the Communications-Electronics officer. He entered the Air Force Institute of Technology Post Graduate Program in June 1974.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This paper is a revision of a digital computer program written to perform a load flow and/or short circuit analysis of a power distribution system. The program has been named Power Distribution System Analysis Program (PDSAP). The program capacity is 250 buses and 500 line elements, with 250 of the line elements being transformers. Input routines accept data as impedances (ohms or per-unit), or as descriptive information such as wire size, length, or transformer ratings. For descriptive data, the program uses pre-calculated approximations to derive the impedance values due to neutral conductors in

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the system. The load flow routine uses the fast-decoupled Newton-Raphson technique and has the capability of changing loads to represent load growth within the system. The short circuit routine analyzes systems in 50 bus groups, simulating various types of faults for each bus. Bus voltages and line currents in the system are calculated for each simulated fault. The paper contains a comprehensive User's Guide which provides clear and concise instructions for operating the program. The PDSAP program is intended for use by anyone in the Air Force with an electrical engineering background and concerned with power distribution.